MATH SOFTWARE

IEEE SPECTRUM

THIN IS IN

The new shape of display technology

NOVEMBER 1993 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.

In fact, they'll do just abou

"Computer, read me today's mail."
These computers will actually speak to you, reading aloud your e-mail, documents or spreadsheet numbers. Our new Apple AudioVision™ Display, with its sensitive microphone and built-in speakers, is the perfect all-in-one monitor for speech capabilities, multimedia presentations and more.

"Computer, call Michelle Dunn."
With Apple GeoPort, you can turn your AV computer (in this case, the Macintosh Centris 660AV) into a telephone and an answering machine. The hands-free phone lets you do work on-screen while you talk. And both computers have ES•F2F software, so all you need is a video camera to hold a video-conference across a local area network.

"Computer, fax letter to Steve Wingate."
Forget the fax machine. The optional Apple GeoPort™ Telecom Adaptor includes fax and modem software–everything you need to send and receive faxes from your desk or use on-line services. And both computers let you try out ExperFax, an application that converts your faxes into text.

t anything you tell them to.

"Computer, open my word processor."
Now work the most intuitive way. With Apple PlainTalk™ AV computers (here, the Macintosh Quadra 840AV) can recognize spoken commands–you just speak naturally. We've also included QuicKeys OSA Component software, so you can create your own verbal commands, like "Computer, open my word processor."

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Just plug a video camera, VCR or laserdisc player into the back of either AV computer. The FusionRecorder software included lets you easily capture video and single-frame snapshots, or record 16-bit stereo sound. You can paste your videos directly into presentations, documents or any software that supports QuickTime.™

"Computer, display Macintosh on TV."
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"Computer, play CD."
Add the AppleCD™ 300i disc drive to either machine, and you can access huge libraries of clip art, sound effects, video clips and more. Or just play your own music CDs while you work.

The Macintosh Centris 660AV and Macintosh Quadra 840AV

You've probably read that telephones, computers, television and other technologies will converge soon.

This is where they meet. Introducing the Macintosh Centris™ 660AV and Macintosh Quadra™ 840AV personal computers. These two computers offer a suite of communication capabilities called Apple® AV Technologies: a telecommunications center, easy video input/output connections, voice recognition and text-to-speech abilities.

Apple AV Technologies.
Telecommunications, video, speech – all the ways you communicate.

For the first time, use a Macintosh® to pick up phone messages with a point and click, record video by plugging in a video source, and open a file by saying, "Computer, open."

Many of these new functions are sped along by a digital signal processor (this chip flies through data at the rate of 55 MHz in the Macintosh Centris and an even faster 66 MHz in the Macintosh Quadra).

With a 25 MHz 68040 processor and up to 68MB of RAM, the Macintosh Centris has the horsepower required to breeze through huge spreadsheets and documents. And there's room to add a 500MB internal hard disk, a CD-ROM or SyQuest drive and a NuBus expansion card.

The new Macintosh Quadra will make publishing, graphic design and other communications professionals salivate. Its 40 MHz 68040 processor and up to 128MB of RAM make it the most powerful Macintosh ever. And it has room for a gigabyte of hard disk storage, four internal storage devices and three NuBus expansion cards.

Best of all, you can get a Macintosh with Apple AV Technologies starting at $2489.* Once again, Apple puts the most amazing kind of power within your reach. The power to be your best.®

Apple

Newslog

SEP 6. Hitachi Ltd., Tokyo, said its researchers had designed a way to use a single silicon atom to electronically switch a binary device. The element could be used to design transistors operating 1000 times faster than today's devices, while taking up less than 1/1000 of the space. A supercomputer using such switches, the company said, could be created that would occupy just 0.2 mm^2 of space.

SEP 9. Toshiba Corp., Tokyo, and **Microsoft Corp.**, Redmond, WA, said they would work together on system software for portable computers and hand-held information devices. For the devices it is developing, Toshiba will license Microsoft's At Work software, a system being designed to link all types of office equipment.

SEP 14. Federal Aviation Administration officials said a U.S. civilian aircraft, guided only by radio signals from four **Global Positioning System** (GPS) satellites 18 000 km up in space, made a 19-km trip down the Potomac River and back to National Airport, Washington, DC. In the demonstration, hailed as a milestone in aviation, the pilots touched the controls only during the takeoff and landing. The GPS, already in use by the military and by marine navigators, is expected to formally begin operating with civilian aircraft late this winter and to be in routine use by mid-1995.

SEP 14. Nynex Corp., New York City, said it had awarded a five-year, US $1 billion contract to **Northern Telecom Ltd.'s** U.S. subsidiary in Nashville, TN, for digital switching systems to be used in Nynex's telecommunications network.

SEP 14. Sprint Corp., Overland Park, MO, and **Kinko's Service Corp.**, Ventura, CA, said they would build a huge public videoconferencing network, allowing customers to make video calls between Kinko's 650 copy centers worldwide or to any company on Sprint's videoconferencing network. About 100 centers are to be equipped by April 1994.

SEP 16. The chairman of a Russian commission recently set up to deal with radioactive pollution in the seas said **Russia** would seal two corroding nuclear torpedoes aboard a sunken submarine next summer, lest plutonium leaked and poisoned fishing grounds in the North Atlantic.

SEP 16. Intel Corp., Santa Clara, CA, and **Sandia National Laboratories**, Albuquerque, NM, and Livermore, CA, announced a technology transfer agreement to boost software applications for scalable, parallel-processing supercomputers. The three-year deal is to commercialize parallel programming technology developed at Sandia in the object-oriented C++ language, including linear equation and eigenvalue solvers.

SEP 20. Japan Satellite Systems Inc., Tokyo, said it had ordered from **Hughes Aircraft Co.**, Los Angeles, its most advanced communications satellite with 40 transponders. The Japanese company plans a launch in August 1995 to expand its varied services into China, the Russian Far East, Southeast Asia, and Australia. Such global services, the first by a Japanese concern, are expected to be allowed after the deregulation of Japan's telecommunications industry.

SEP 22. The **space shuttle Discovery** ended a 10-day mission with the first nighttime landing at Kennedy Space Center, Cape Canaveral, FL. Discovery's crew completed a spacewalk and deployed two satellites: the Advanced Communications Technology Satellite, known as a high-tech switchboard in the sky, and a reusable German telescope for star gazing, which the crew brought back with them.

SEP 23. The Federal Communications Commission (FCC), Washington, DC, said it would auction off up to $10 billion in licenses for personal communication services networks. By a vote of 2 to 1, the FCC said next May it would award 2500 licenses—three times the number now devoted to cellular phone service—for new wireless services. As many as seven licenses could be awarded in every U.S. city: two 30-MHz blocks of spectrum in each of 49 large regions, as well as a 20-MHz block and four 10-MHz blocks in 492 subregions.

SEP 27. Nippon Sanso Corp., Tokyo, and **Taiyo Sanso Co.**, Osaka, announced a pact to jointly develop devices to refine, supply, and recycle special gases for the manufacture of 64-megabit dynamic RAMs over the next four years.

SEP 27. NEC Corp., Tokyo, said it and **AT&T Co.** had agreed to jointly develop technologies for producing application-specific ICs (ASICs) with a 0.35-μm linewidth. The two companies plan to develop these technologies in 21 areas for cell-based ASICs, including lithography, etching, and design. They hope to complete the project by June 1995.

SEP 29. The White House and the **Big Three U.S. auto makers** announced a radical new approach to car technology and Government-industry relations. Under the agreement, Washington will give Detroit technology from weapons programs, and Detroit, over the next 10 years, will strive to build a car that will triple fuel efficiency to the equivalent of about 80 miles per gallon (3 liters per kilometer). The vehicles would be lighter in weight than today's cars and run on fuel cells or advanced energy storage systems.

SEP. 29. U.S. President Bill Clinton announced a proposal to liberalize U.S. high-technology exports, setting a goal of boosting exports from about $700 billion in 1992 to $1000 billion by the year 2000. The first phase would free exports of computer workstations and high-performance PCs to all countries except the former Eastern Bloc, China, and a few others. The second phase, if the Paris-based Coordinating Committee for Multilateral Export Controls agrees, would in addition decontrol multiprocessor servers, high-end workstations, minicomputers, and some mainframes.

SEP 30. Martin Marietta Corp., Bethesda, MD, said that it had eliminated 9000 jobs nationwide this year. The company, which last year bought the **General Electric Co.**'s aerospace electronics division, said it would also close 10 production sites in seven states and cut another 2000 employees to consolidate the two businesses and reduce the company's operating costs by $1.5 billion over the next five years.

OCT 1. National Aeronautics and Space Administration (NASA) researchers said they have recorded for the first time huge flashes of light—some 40 km long—in the upper atmosphere above a severe thunderstorm. They said the flashes were as yet unexplained, but could be electrical discharges, which could present problems for high-altitude airplanes.

Preview:

NOV 16. The prototypical **Earth Data Systems network**, linking computers by phone lines at nine sites across the United States, is to be demonstrated at the **Supercomputing '93 Conference** (Nov. 15–19) in Portland, OR. The network will let users share 20 years of environmental data on tropical deforestation and ocean pollution. For more conference information, call 202-371-1013.

Sally Cahur

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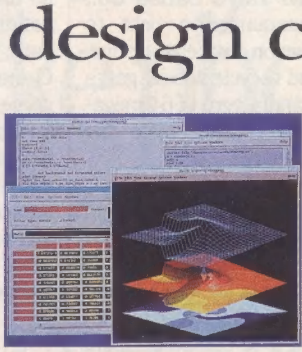

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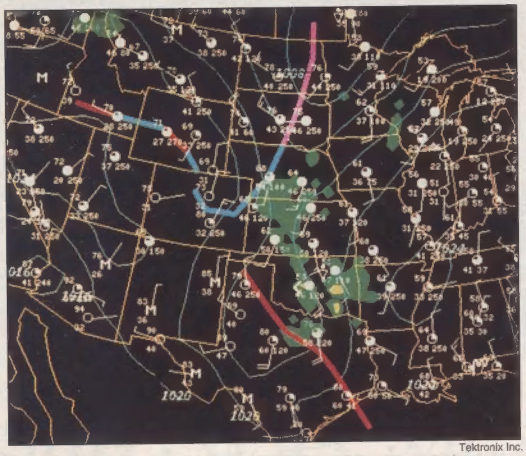
IEEE SPECTRUM

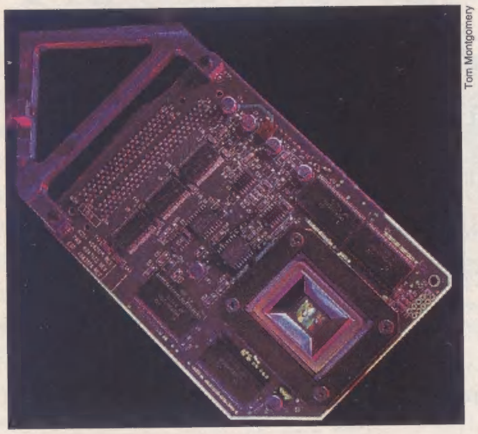
PERSPECTIVE

By KENNETH I. WERNER

After investing billions of dollars, makers of flat-panel displays are on the verge of shipping color active-matrix units in volume. But the high cost of developing and building them may let other designs—like the plasma-addressed screen at right—use their technical advantages to grab a share of the market.



Tektronix Inc.



Tom Montgomery

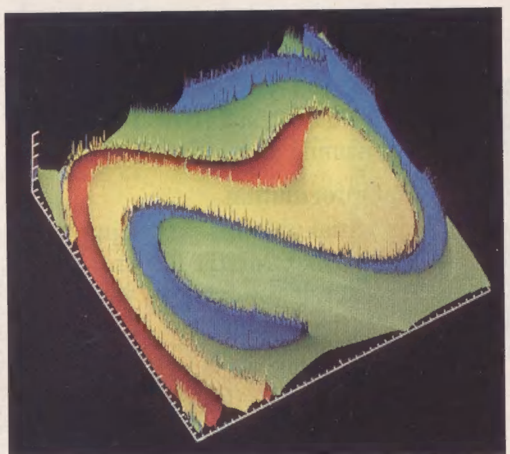
By JACK M. YOUNSE

Half a million aluminum mirrors are suspended like tiny seesaws above a static RAM chip. They create images by reflecting light in one or other direction at the bidding of the memory cell data. Standard semiconductor production equipment suffices for these devices, which form the heart of a new digital projection-display technology.

ADVANCED TECHNOLOGY

By EARLE R. HUNT and GREGG JOHNSON

The latest work in the study of chaos hinges on techniques for controlling it. Among systems controlled so far are a rabbit's heart, electronic circuits ranging from simple diode-inductor pairings to exotic lasers, and several mechanical systems, including one that produced the map, or attractor [right], of the motions of a double-potential-well system.



Ohio University

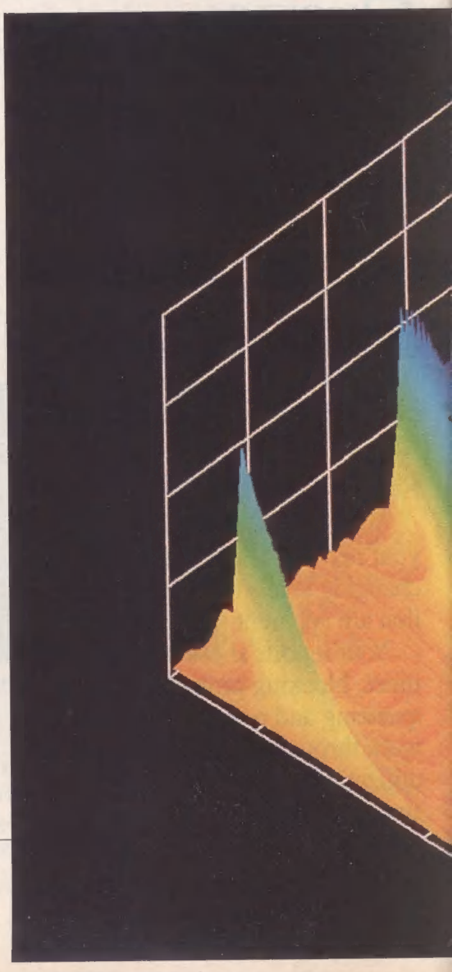
FOCUS REPORT

SOFTWARE

More than 160 math, visualization, and data acquisition tools for engineering and science are featured in *IEEE Spectrum's* fourth annual Focus Report [pp.37–87].

By GADI KAPLAN

In virtually all design and analysis situations, mathematics, data analysis, and visualization software tools have been playing a bigger role, as reflected by the wealth of programs now available. One example is an ambiguity diagram of a radar receiver's response over target range and velocity [below] produced by the SPW package from Comdisco Systems Inc. At the same time, data acquisition remains central to many scientific experiments and to the evaluation of ever more complex systems.



Comdisco Systems Inc.

Cover: The half million or so mirrors of Texas Instruments Inc.'s digital micromirror device reflect red, blue, and green light in sequence to project an extremely sharp and colorful image of a group of bikers. Photographer Steve Kelly took the picture, which was stored digitally on a compact ROM. Data from the ROM was fed to the CMOS static RAM whose cells underlie and control the micromirrors. See p. 27.

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Editorial Board

Forum

How resourceful are we?

Raymond S. Larsen's article "Running out of resources" [July, pp. 43–45] evoked such a quantity and diversity of comments that we have devoted a separate section to them and to Larsen's response. See pp. 11–13. —*Ed.*

A real doctor

As an EE (Ph.D. 1986) and a practicing physician (M.D. 1982) who dabbles in medical expert systems, I read with special interest the letter by P. T. Burnett advocating publicly located expert systems "for diagnosing typical ailments and for prescribing appropriate treatments" [July, p. 8]. Such a suggestion demonstrates an incomplete understanding of how medical diagnosis and treatment is carried out in the real clinical world.

For instance, subtle aspects of grooming, facial appearance, tone of voice, and other not easily quantified clinical features are exceedingly difficult to integrate usefully into medical expert systems. Yet they sometimes matter greatly in the art of clinical medicine, especially when psychological aspects enter the clinical picture. While medical expert systems may be useful in specialized areas (for example, interpretation of pulmonary function tests), I would no sooner employ a general medical expert system as a primary source of medical advice than I would employ a general legal expert system to prepare a legal defense.

D. John Doyle
Toronto

A question of creativity

The article "Blue lasers on the horizon" [May, pp. 28–33] reported on the long-awaited progress of blue laser diodes and light-emitting diodes (LEDs). Researchers are inventing designs using these diodes, for which patents may be granted if the researchers apply for them.

Though the authors mentioned some applications of blue laser diodes and LEDs, these already use similar, existing products. Therefore, in my opinion, any such applications may not be patentable creations.

For example, a red laser diode is used in the read mechanism of compact discs. By replacing the red laser diode with a blue one, the memory capacity doubles. Replacement with a blue laser diode, however, can be easily imagined by anyone in this business. Arrays (chips) of red laser diodes, green laser diodes, and blue laser diodes may replace the light/image sources of projection television receivers; then, the arrays may replace cathode-ray tubes.

These replacements will take place in commercial TVs, airplane cockpits, automobile dashboards, and displays of laboratory and industrial instruments, to mention a few. A monochromatic graphic display with a liquid-crystal display or a gas-discharge dot matrix will be replaced and improved with these new components, changing them to multiple colors.

A similar relationship occurred between vacuum tube triodes and transistors. Before the invention of the transistor, amplifiers, oscillators, mixers, flip-flops, gates, and many other circuits had been made with triodes. In circuits, the triode of the three-terminal device could be readily replaced with a transistor that was also a three-terminal device. Since the transistor was novel, engineers and their employers thought the simple replacements were a new invention. Because the patents on many of those replacements were still pending then, there was confusion in the industry.

The invention of the transistor was followed by the invention of various semiconductor components, such as analog and digital ICs, photo diodes, photo transistors, and laser diodes. Over the years, engineers developed the technical practice of replacing an old component with a new one. By following this practice today, we can easily and mechanically list most, if not all, *simple, generic replacements* with blue laser diodes and blue LEDs in various types of equipment and vehicles—without inventive effort.

I, however, recognize broad technical areas for invention still remain, since creation is required in order to realize a simple, generic replacement. For example, a new mounting design of a laser diode and a new servo-mechanism will be required in the read-out section of a high density compact-disc product.

We engineers and business managers should agree that simple, generic replacement with the newly invented components is not a patentable creation, although a design for the realization of the replacement may be patentable. I would like to hear the opinions of other members.

Masahiro Kazahaya
Warminster, PA

Technical publishing

I do not believe that Dale A. Wood is correct that all Ph.D. dissertations from major U.S. universities are available from University Microfilms Inc. (UMI) [June, p. 6]. After expressing my objection to signing the UMI agreement, a requirement of the dissertation filing procedure at the University of California at Los Angeles, I was allowed to attach a letter that prevents UMI from providing access to my dissertation. (Since dissemination of a dissertation has important consequences related to disclosure of potentially patentable ideas, I would contend that, in fact, a more systematic procedure for blocking the publication of a dissertation should be developed.)

Whether or not a specific dissertation is technically "published," the concept of the "unpublished dissertation" is highly meaningful from a functional standpoint. It is, to my knowledge, universally accepted that work documented in a Ph.D. dissertation may be submitted to professional journals. If the material is considered already published in the dissertation, then this state of affairs would constitute a multiple submission, which is impermissible.

While a great deal of important research is documented in Ph.D. dissertations, their status as publications (under a broad definition that includes them) is rather low, which is evident by the fact that they, unlike articles extracted from them, are not often cited in reference lists.

Lance B. Sjogren
Los Angeles

Corrections

On p. 3 of the September issue, the June 16 item in Newslog should have located the European Commission meeting in Luxembourg, Luxembourg.

On p. 3 of the October issue, the Preview item in Newslog was incorrect. The date slated for the damages trial of Borland International Inc. for infringing on Lotus Development Corp.'s 1-2-3- spreadsheet is Oct. 3, 1994. —*Ed.*

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*, on the policies and operations of the IEEE, and on technical, economic, or social matters of interest to the electrical and electronics engineering profession. Short, concise letters are preferred. The Editor reserves the right to limit debate. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, NY 10017-2394, U.S.A.; fax, 212-705-7453. The Internet (e-mail) address is n.hantman@ieee.org. The computer bulletin board number is 212-705-7308 and the password is SPECTRUM; for more information, call 212-705-7305 and ask for the Author's Guide.

Calendar

Meetings, Conferences, and Conventions

NOVEMBER

International Conference on VLSI and CAD (ED); Nov. 15–17; Hotel Riviera, Yusong, Taejon, Korea; Kwyro Lee, Department of Electrical Engineering, Kaist, 373-1 Kusong, Yusong, Taejon, Korea; (82+42) 869 3433; fax, (82+42) 869 3530.

38th Conference on Magnetism and Magnetic Materials (MAG); Nov. 15–18; Hyatt Regency Hotel, Minneapolis, MN; Janis Bennett, American Institute of Physics, 500 Sunnyside Blvd., Woodbury, NY 11797; 516-576-2403; fax, 516-349-0247; or Diane Suiters, Courtesy Associates, 655 15th St., N.W., Suite 300, Washington, DC 20005; 202-639-5088; fax, 202-347-6109.

LEOS Annual Meeting (LEOS); Nov. 15–19; San Jose Convention Center, CA; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-389.

19th Conference of Industrial Electronics (IE); Nov. 15–19; Hyatt Regency Maui, Maui, HI; Robert J. Roman, 3685 Oak Rim Way, Salt Lake City, UT 84109; 801-277-1456; fax, 801-223-1456.

Supercomputing '93 (C); Nov. 15–19; Oregon Convention Center, Portland; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Optcon '93 (LEOS); Nov. 16–18; San Jose Convention Center, CA; Cathy Goldsmith, IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855-1331; 908-562-3894; fax, 908-562-1571.

Second Asian Test Symposium—ATS (C); Nov. 17–18; Friendship Hotel, Beijing, China; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

ATM Seminar (C); Nov. 18; United Engineering Center, New York City; Jim Barbera, Metro Services Group, 333 Seventh Ave., 20th Floor, New York, NY 10001; 212-594-7688; fax, 212-465-8877; or Bob Puttre, 914-644-2849.

Central America and Panama Conference—Concapan XIII (Costa Rica); Nov. 18–20; Centro de Convenciones dei Hotel Cariari, San Jose, Costa Rica; Comite Organizador, APDO 2346–1000, San Jose, Costa Rica; (506+5) 354 28; fax, (506+2) 497 74.

International Photovoltaic Science and Engineering Conference (ED); Nov. 22–26; Nagoya Congress Center, Japan; Masafumi Yamaguchi, NIT Opto-electronics Laboratories, Tokai, Ibaraki 319–11, Japan; fax, (81+29) 287 7880.

Third International Conference on Power Cables and Accessories 10kV to 500kV (UKRI Section); Nov. 23–25; Institution of Electrical Engineers, London, UK; Louise Bousfield, Conference Organiser, IEE Conference Services, Savoy Place, London, WC2R OBL, UK; (44+71) 240 1871, ext. 325; (44+71) 497 3633.

Global Telecommunications Conference—Globecom '93 (COM, et al.); Nov. 29–Dec. 2; Westin Galleria Hotel, Houston, TX; Robert A. Finley, Southwestern Bell Telephone, 6500 West Loop S, Zone 3.3, Bellaire, TX 77401; 713-567-8127; fax, 713-567-6133.

Communication Theory Mini-Conference (COM, IT); Nov. 29–Dec. 3; Westin Galleria Hotel, Houston, TX; Peter J. McLane,

(Continued on p. 90)

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 80055; 908-562-3878; submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017; 212-705-7305.

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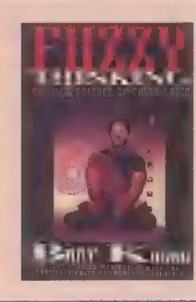
Books

Getting lucky with fuzzy logic

Earl Cox

Fuzzy Thinking: The New Science of Fuzzy Logic.
Kosko, Bart, Hyperion, New York, 318 pp., $24.95.



I had to read Fuzz-Sensei Bart Kosko's strange yet enthralling tale of fuzzy logic, Zen mysticism, neural metaphysics, and differential topology not once but twice—once for understanding, and again for enjoyment. To those of us who have read Kosko's recent *Neural Networks and Fuzzy Logic: A Dynamical Systems Approach to Machine Intelligence*, and his previous tome on signal processing, this book comes as quite a surprise. In one fell—and often strident and mildly egocentric—swoop, the professor of electrical engineering at the University of Southern California in Los Angeles does the following:

- Dispels our 2400-year-old belief in a bicameral sense of order and logic.
- Compares and contrasts the Buddha with Aristotle, Hume, Georg Cantor, David Hilbert, and even Bart Kosko.
- Places the Pythagorean theorem at the center of all physical phenomena and explains the true meaning of Heisenberg's uncertainty principle.
- Ties fuzzy reasoning to Palestinian terrorism and the fall of Lebanon, the definition of life, the question of abortion, the Western jurisprudence system, and, last but not least, optimal methods for seducing your date.
- Explains why the mind thinks and learns in terms of energy manifold sculpting.
- Bases the existence of the universe, the weak anthropic principle, the case for quantum gravity, and a new vision of God ("The Math Maker") on the fact that you can't divide by zero.

Mind you, this is only a small selection of the potpourri of facts, ideas, conjecture, and equations that Kosko skillfully blends in a book that is rich, sometimes obscure, but always thought provoking. Kosko seems to delight in jumping headlong into the fray, striking out at advocates of the status quo in logic, mathematics, science, engineering, and everyday life. But he does so in a well-reasoned and carefully crafted manner, using his own vision of the world and his skill as a mathematician and fuzzy reasoner to expose flaws in the way scientists and philosophers have viewed the mechanics of the universe since well before the time of Aristotle.

He blames Aristotle, most of all, for this sorry state. Aristotle's insistence that the intersection of a set with its complement is always empty (the A and NOT-A view) laid the foundation for the ascendancy of binary, or Boolean, logic. Kosko complains (rightly so) that we have rejected Aristotle's silly physical laws (heavier objects fall faster than lighter ones, an arrow is pulled along its trajectory, and so on) and embraced his logical ones—despite the fact that we see around us countless examples of gray areas they cannot handle.

Kosko's mantra is "Hey! What's wrong here?" There are plenty of examples that provoke it, and not just simple ones. He makes some bold assertions, and backs them up with his own mathematical theorems and systems. Among the grander claims: probability and Boolean logic are just special cases of fuzzy logic; fuzzy numbers exist; "true" artificial intelligence, which is the quest for intelligent machines, has run into a dead end because it turned away from fuzzy logic.

The question at the heart of the book is: exactly what is fuzzy logic? In some ways, Kosko answered it from a mathematical viewpoint in his previous book, thereby joining the ranks of academics who parade their command of fuzzy arcana. For this book, on the other hand, he has apparently thought long and hard about the implications of fuzzy logic and its impact on society. The result is a plain, breezy account of how Kosko came to understand the deeper meanings of fuzzy logic and how that understanding changed his way of thinking. In telling the story, he weaves together anecdotes from his personal life (I wish there had been more) and professional career (including his relationships with Lotfi Zadeh, the inventor of fuzzy logic, and the Japanese fuzzy community). There are also stories about science and business, and enough technical and mathematical tidbits to tempt the intelligent reader.

Readers interested in fuzzy logic and how it relates to traditional logic and probability will not be disappointed. Kosko does a fine job of elucidating the shortcomings of bivalent logic. He explains how he wrestled with the duality of fuzzy logic and probability for a long time before suddenly discovering a simple, unifying idea. The core of the book is a well-reasoned and coherent examination of the emerging fuzzy logic and neural network paradigms.

Nevertheless, the book is often flawed by Kosko's tendency to glibness. For example, he makes abrupt transitions from discussions of n-dimensional fuzzy spaces and Shannon's information theory to statements like "It's all Fuzz," one of his favorites. On the one hand, he assumes the reader knows little mathematics or fuzzy logic, but on the other he rushes right over Planck's constant (actually, h-bar), linear time-invariant systems, and the Cauchy-Schwarz inequality, remarking that he "found it a great let-down when [he] first learned that Heisenberg's uncertainty principle was just the well-known Cauchy-Schwarz inequality in physics disguise."

On the whole I would have preferred a little more depth in some of Kosko's observations about these physical phenomena, especially those concerning nonlinear systems, which he mentions many times. And it is sometimes difficult to separate Kosko's beliefs from scientific fact. The two are not often at odds, but he does have very strong opinions.

As you might have guessed by now, this is an ambitious book. On the whole it works well and I recommend it to anyone interested not only in fuzzy logic, but in the general issues of scientific method, the limitations of our explanatory processes, and, of course, the rise of machine intelligence. Kosko's interests range from music (he composed the background music to his own video course on fuzzy logic) to philosophy and Eastern religions, and he seems to be emerging as the Leonardo da Vinci of the world of intelligent machines.

Earl Cox is founder and chief executive officer of the Metus Systems Group in Chappaqua, NY. Before that, he was founder and president of Knowledge Based Technologies Inc. in White Plains, NY. His Handbook of Fuzzy System Modeling will be published next January by Academic Press's Professional imprint in Boston.

Lowell's legacy

Gilbert V. Levin

The splendid cover of this mammoth tome provides an overdue fresh look at the color of the so-called "Red" Planet. This might be interpreted to promise a new look at the other key debate about Mars—life. Alas, you still can't judge a book by its cover!

In 38 chapters, 114 authors present facts and theories about Mars, including its history and cultural significance; composition, mineralogy, and internal structure; topography and surface features, geodesy, car-

tography, and stratigraphy; volcanism, cratering, and channels; atmospheric water and regolithic ice; climate changes; atmospheric composition and dynamics; dust and aeolian processes; physical and chemical weathering; the chemical activity of its surface material; the possibility of past or present life; magnetic field and solar wind; and the origin, geodesy, and cartography of its moons. There are 18 color plates, and accompanying sepia topographic and colored geological wall maps of the polar and equatorial regions.

Unfortunately, the editors have not arranged this sprawling survey in accordance with the relative significance of the many subjects it addresses. This is abundantly clear in the inadequate and unbalanced treatment of the possibility of life. For example, the chapter by R.O. Pepin and M.H. Carr entitled "Major Issues and Outstanding Questions" devotes only a half dozen glancing sentences to that vital question about Mars. Therefore, this review will deal primarily with the book's (mis)treatment of that issue.

Likewise, "The Search for Extant Life on Mars" by H.P. Klein, N.H. Horowitz, and K. Biemann—the sole chapter devoted to the *raison d'être* of the billion-dollar Viking project—fills a mere 0.7 percent of the book. The editors did not seek input from this reviewer, the Viking experimenter whose Labeled Release (LR) experiment provided strong evidence of living microorganisms on Mars. Instead, the LR data are co-opted by the chapter's authors as evi-

MARS. *Kieffer, H., et al., eds., University of Arizona Press, Tucson and London, 1992, 1498 pp., $65.*

dence *against* life and *for* putative oxidants in the soil. While this chapter does cite the works of 10 scientists representative of those who "feel there may well be active biology on Mars," their cases are not presented.

Omitted is the fact that the results of nine LR experiments on Mars exceeded the criteria for the detection of life. These criteria had been accepted, prior to launch, by the Viking Biology Team (including two of this chapter's three authors), and by all the review committees. The authors also ignore intensive research and remote sensing from earth and Mars orbits that failed to support the oxidants thesis.

The authors' main argument against the LR experiment is that the Gas Chromatograph Mass Spectrometer (GCMS) Experiment of coauthor Beimann found no organic matter on Mars. The authors fallaciously dismiss important evidence that the LR found living microorganisms in a sample of Antarctic desert soil in which the GCMS was unable to detect any trace of organic matter. Their proposal is that the soil had become contaminated in the years before it was tested by the LR.

Actually, no such interval occurred. Because the GCMS results were not published until years later, the *comparison* was delayed. The late GCMS report also revealed that a standard chemical test of the same sample did find organic matter. As Biemann states, the GCMS requires the organic content of one million living cells to produce a response. The LR detects as few as 10 cells.

The chapter omits any reference to work by Horowitz indicating that organic matter in amounts that "could be considerable over geological time" are formed on Mars. Other important evidence for organic compounds on Mars is neglected: the SNC meteorites (generally agreed to be of Martian origin) contain organic compounds, and the infall of interplanetary dust

Books

delivers thousands of tons of organic-laden particles to the surface of Mars annually.

According to Klein and coauthors, Mars was "de-Lowellized" (the verb is a swipe at the late U.S. astronomer Percival Lowell, who was convinced that the existence of water permitted Mars to be inhabited by intelligent life) by Mariners 4, 6, 7, and 9, which revealed that "liquid water could not exist on the surface," making the search for life an impossible quest for Viking.

This would perhaps come as a surprise to B.M. Jakosky and R.M. Haberle, who report in another chapter on "The Seasonal Behavior of Water on Mars." They cite the exchange of atmospheric water vapor with the Martian surface and discuss the availability of water as a pure liquid or as a brine or ice. Fog and frost were seen at both Viking landing sites. One wonders whether Martian organisms, deprived of water over time, might have evolved to glean water from atmospheric vapor, as do some lichen on earth, or to exist within the few layers of liquid or absorbed water cited by Jakosky and Haberle. After all, life on earth could not exist if plants had not evolved the ability to scavenge carbon dioxide from the scant 0.03 percent present in the atmosphere.

In "The Possibility of Life on Mars During a Water-Rich Past," C.P. McKay and his coauthors speculate that the loss of water on the planet—which had a temperate climate and flowing water for a period longer than that which gave rise to life on earth—might have killed any existing life. They therefore advocate a search for fossil evidence.

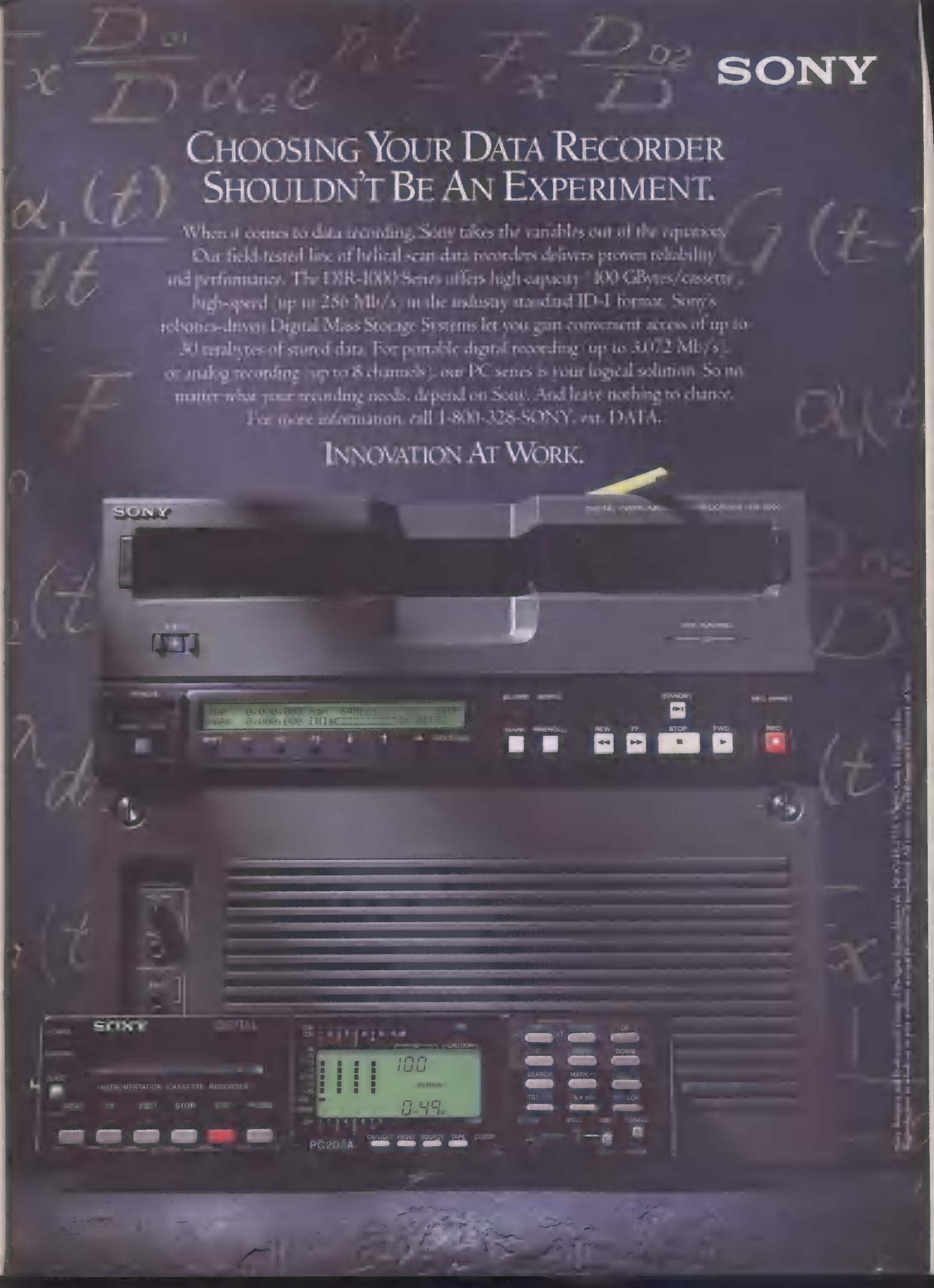
A. Banin and coauthors, in "Surface Chemistry and Mineralogy," also use the LR data, not as evidence of life or oxidants on Mars, but rather of clays. In claiming to have duplicated the LR Mars data, they ignore published criticism that their unsterilized clays would readily produce an LR response.

As to the debate over the planet's color, Viking's first image of the Mars landscape showed an Arizona-desert–like landscape under a mild blue sky. This was quickly adjusted to a monotonously red landscape and a salmon-pink sky, which became the official version. Hence my surprise at the sudden reappearance of the Arizona-type landscape gracing this book's cover, even if the accompanying Hoagie Carmichael buttermilk sky still does not comply with the cerulean hue that Rayleigh scattering would seem to require. This provocative color issue is confined to one brief paragraph in "The Martian Surface Layer," by P.R. Christensen and H.J.Moore, who remain in the red camp. No other author approaches the subject.

Any atmosphere of colorless gases (as is Mars's) lets the sun's red light through but scatters the blue, which colors the sky. A red sky therefore requires that the atmosphere preferentially scatter red light. Proof that direct, not scattered, sunlight provides the predominant illumination on Mars is provided by the dark shadows of rocks. In scattered light, those areas would be lit. Were red light scattered by dust or other means, the landscape (and the Viking color-calibration chart) would have appeared biased toward the blue.

The main question raised by this book concerns not Mars, but why *Mars*'s contributors and editors so carefully tiptoed through the data. Is it fear of tar from Lowell's brush, peer (review) pressure, politics, or some combination thereof? Alas, the answer is not to be found in this book.

Gilbert V. Levin is president of Biospherics Inc., Beltsville, MD. He has conducted research on microbial industrial processes and methods for the rapid identification of microorganisms. As a member of the Mars Oxidant Team, he is helping prepare an experiment selected by NASA for the Russian 1994 Mars Lander to investigate the reactions detected on Mars by his LR life detection experiment and others.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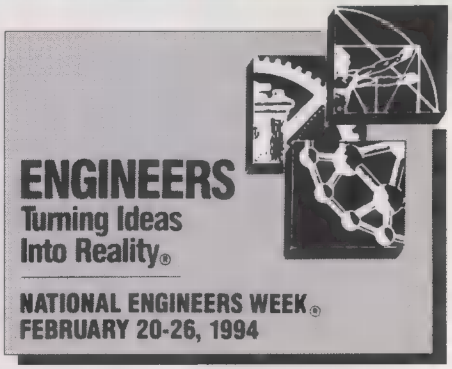
IEEE-USA Puts Information On Internet and Compmail

IEEE United States Activities has expanded its electronic mail services. Autoresponse files can now provide U.S. members with information on member services, Federal Government actions, meetings, and publications.

In response to e-mail messages sent to IEEE-USA addresses, corresponding text files are sent automatically. Addresses for Compmail users are listed. Internet users should add, without spacing, **@ieee.org** to all Compmail addresses. Files now available include:

- **Employment Assistance**—Information on various forms of assistance, including commercial on-line job listings; **info.ieeeusa.employ**
- **Legislative Report Newsletter**—Offers insights into current Congressional activities; **info.ieeeusa.legrpt**
- **Federal Legislative Agenda**—Summarizes IEEE-USA's recommendations on such key issues as industrial competitiveness, retirement income, defense conversion, R&D, and other policies; **info.ieeeusa.agenda**
- **Position Statements**—IEEE-USA's recommendations on various career and technology policy issues; **info.ieeeusa.pos**
- **Pensions Update**—The latest information, including the current status of such legislation; **info.ieeeusa.pension**
- **Influencing Public Policy**—Offers useful tips on how members can improve their ability to influence public policy; **info.ieeeusa.lobby**
- **Conferences**—Advance programs and registration information for IEEE-USA conferences; **info.ieeeusa.conf**
- **Publications**—Titles of sale and free publications and ordering information; **info.ieeeusa.pubs**

A complete list of IEEE's autoresponse files is also available; **info.info** ✦



Job Fairs Update

IEEE cosponsored job fairs are tentatively scheduled at these locations during the remaining months of 1993.

DATE	LOCATION
November 8-9	Detroit Section (PE)
November 8-9	Nat'l Capital Area Council (LG)
November 15-16	San Jose Section (LG)
December 6-7	Santa Clara Section (W)

Job fairs are open to all engineers. For more information concerning the locations of the fairs marked (LG), please call (800) 562-2820; Virginia residents should call (800) 533-1827. For fairs marked (PE), call (800) 338-4530; and for fairs marked (W), call (408) 970-8800. In all cases, ask for the IEEE Career Fair Coordinator.

Attention Job Seekers . . .

For a complete roundup of IEEE-USA's employment assistance efforts, see IEEE-USA's *Professional Perspective* insert in the September-October issue of *The Institute*. More information is also available from the IEEE-USA Office in Washington, D.C., or by electronic mail on an autoresponse file: **info.ieeeusa.employ@ieee.org** on Internet. ✦

Conference To Explore Engineering Leadership

IEEE-USA will hold its eighth biennial Careers Conference on April 14-15, 1994, in Ft. Worth, Texas. With the theme, "Every Engineer a Leader: Learning and Leading in Today's Organizations," the Conference will explore such topics as engineering leadership, engineers and global competitiveness, creating a learning organization in the engineering community, diversity in the workplace, and organizational practices that help build technical leaders.

U.S. Representative Pete Geren (D-Texas) will be the luncheon speaker on April 15.

Engineering and human resource managers, academics, engineers, scientists, and other technical professionals are encouraged to attend this two-day conference to share and gain insights into engineering careers, management, team-building, and leadership issues. To receive additional information or to register please contact the IEEE-USA Office in Washington, D.C. ✦

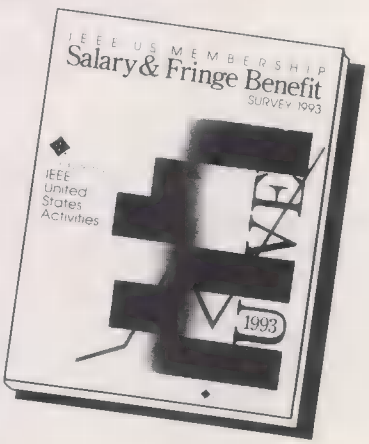
Circle No. 20

1993 Salary Survey Available

The *1993 IEEE U.S. Membership Salary and Fringe Benefit Survey* offers detailed information on salaries and benefits of electrical, electronics, and computer engineers, as well as employment data and demographic and occupational characteristics. Questionnaires were sent to nearly 21,000 randomly selected members and yielded more than 6,000 responses.

The most significant change this survey revealed since the 1991 survey was taken involves unemployment, with involuntary unemployment at the highest rate ever recorded. Only 77 percent of respondents reported full-time employment. However, the survey showed that average income since 1991 has risen at a rate slightly faster than inflation for the declining numbers of engineers working full time in their own field.

The 1993 survey report is available to members for $74.95 and to nonmembers for $119.95, plus $6 postage and handling. To order, call IEEE's Service Center at (800) 678-IEEE and ask for IEEE Catalog No. UH0194-1. ✦



Protect Your Retirement: Support Portable Pensions

Many of IEEE's U.S. members incur substantial reductions in pension benefits due to frequent job changes during their professional careers, in spite of widespread pension coverage among employers of engineers and scientists. If recent events indicate future trends, the frequency of job changes will increase markedly in the years immediately ahead as more companies scramble to reduce costs in the face of continuing cuts in defense spending and an increasingly competitive global marketplace.

IEEE-USA Backs Portable Pensions Legislation

A legislative proposal based on IEEE-USA's retirement income policy recommendations was introduced in the U.S. House of Representatives earlier this year. H.R. 1874, the **Pension Portability Improvement Act**, would increase the adequacy and efficiency of the private pension system. This legislation would:

- **Reduce vesting requirements** from five to three years;
- **Improve pension portability** by permitting vested employees to transfer earned benefits from one retirement savings plan to another; and
- **Preserve pension assets** through direct transfers of vested benefits to individual retirement accounts (IRAs) or other portable pension plans.

How You Can Help

Communicate your support for the **Pension Portability Improvement Act** to your U.S. Representative in Washington, D.C. Explain why it's important to reduce vesting requirements, guarantee transferability of pension benefits, and promote pension preservation. Urge your Representative to enact portability improvement legislation during the current Congress.

Shorter vesting, guaranteed portability, and increased preservation of earned pension benefits will improve the retirement income security of increasingly mobile American workers. These reforms will also increase the flexibility and productivity of millions of managerial, professional, and technical personnel in all sectors of the nation's economy.

Letters From Constituents Are Effective

Simple, straightforward letters are the most effective and economical way to communicate your concerns to Members of Congress. Persuasive letters from a substantial number of IEEE's U.S. members could mean the difference between success and failure in our efforts to improve pension portability for all American workers.

Take a few minutes to write a letter to your Representative, even if you already have a portable pension, so that other engineers and scientists can be helped.

Where to Send Your Letters

Address your letters to the U.S. House of Representatives, Washington, D.C. 20515. Consult the reference pages of your telephone book or local public library for further assistance in identifying your Representative.

For tips on communicating with Congress or more information on pension issues and legislation, contact Vin O'Neill at the IEEE-USA Office in Washington, D.C.; send e-mail to **v.oneill@ieee.org** (Internet). ✦

Circle No. 21

IEEE United States Activities

Announces the 22nd Annual Competition for

1995 Congressional Fellowships

PROGRAM: Electrical and Electronics Engineers and Allied Scientists are competitively selected to serve a one-year term on the personal staff of individual Senators or Representatives or on the professional staff of Congressional Committees.

PURPOSE: To make practical contributions to more effective use of scientific and technical knowledge in government, to educate the scientific communities regarding the public policy process, and to broaden the perspective of both the scientific and governmental communities regarding the value of such science-government interaction.

CRITERIA: Fellows shall be selected based on technical competence, on ability to serve in a public environment, and on evidence of service to the Institute and the profession. Specifically *excluded* as selection criteria are age, sex, creed, race, ethnic background, and partisan political affiliations. However, the Fellow must be a U.S. citizen at the time of selection, must have been in the IEEE at Member grade or higher for at least four years, and must have at least 10 years' professional experience, which may include graduate education.

APPLICATION: Further information and application forms can be obtained by calling Chris J. Brantley at (202) 785-0017, by faxing (202) 785-0835, by electronic mail to c.brantley@ieee.org (Internet), or by writing:

Congressional Fellows Program
IEEE United States Activities
1828 L Street, N.W.
Washington, D.C. 20036-5104

Applications must be postmarked no later than March 31, 1994 to be eligible for consideration.

Circle No. 22

Washington watch

What the Medicis were to Renaissance art, Washington, DC, is to 20th-century technology. The U.S. government contributes nearly half the $150 billion invested yearly in U.S. scientific and technical endeavors.

Semiconductors, computer networks, and satellite positioning systems are just a few of the beneficiaries. More dubious ventures have included nuclear-powered aircraft and ballistic missile defense initiatives.

As the current Administration takes on a more activist role in technology R&D, IEEE Spectrum *inaugurates this monthly column of news and service items for its U.S. readership. Ideas or comments may be sent to John Adam, j.adam@ieee.org.*

Defense conversion project draws 2800 responses

The Technology Reinvestment Project (TRP) has been newly set up as the cornerstone of U.S. defense conversion efforts. It recently drew over 2800 proposals worth US $9 billion all told, from industry, state and local governments, and academia. The Government has allotted it $472 million in funds that must be matched.

Of three TRP categories, more than 1900 proposals, worth $7 billion, were in technology development. The hottest topics were in information technology, vehicle development, environment, health care, and materials. The second category, technology deployment, drew more than 550 of the proposals, calling for $1.5 billion in funds to use existing technology for near-term commercial and defense products. In the third category, manufacturing education and training, another 350 proposals, requiring $500 million in funds, were submitted for consideration.

The proposals are being evaluated by teams from half a dozen U.S. agencies: Defense, Commerce, Energy, and Transportation, the National Aeronautics and Space Administration (NASA), and the National Science Foundation. Winners were to be announced from late September on.

A side benefit of the program is that it brings together diverse regional groups, which may continue to cooperate in the future whether they win or not, noted ex-NASA chief Richard Truly, now vice president of the Georgia Tech Research Institute, Atlanta, one of the organizations that submitted proposals.

Minuscule warriors

You heard it here first. The Pentagon's threat is clearly shrinking, to the point of being minuscule. No less a source than the RAND Corp., a primary Department of Defense think tank in Santa Monica, CA, discusses microrobots on p. 101 of its recent annual report. These would navigate from cannisters by flying, gliding, or "some other insect-like motion" and disable enemy electronic systems by a mechanism as simple as spraying a caustic or conducting fluid onto the equipment. For these millimeter-scale robots, fuel need only be a small percentage of their weight. Microrobots are a "leap that some, the Japanese, for example, are beginning to take."

Beware of those cockroaches.

A second look at . . .

...running out of resources

Last July, IEEE Spectrum *published an article entitled "Running out of resources" [pp. 43–45], in which author Raymond S. Larsen voiced his concern about the accelerating pace at which the earth's resources are being consumed. More specifically, he pointed out that IEEE members, if only because of our Constitution, have a special obligation to consider the effects of technology on our environment, and to air their concerns for the public good.*

Because of the possibly controversial nature of some of Larsen's ideas, the editors of Spectrum *explicitly invited comments on the article. And we received a fair number. By regular mail, e-mail, and fax, some 44 readers from around the world have shared their thoughts with us. This is a summary of their responses.*

Overall, we would categorize 28 of the responses as agreeing with Larsen, and 16 as disagreeing. But those numbers may be misleading since not everyone who agreed with him agreed with everything he said, and some who disagreed with his analysis nevertheless found themselves in substantial accord with one or more of his conclusions.

As editors, we were pleased to learn that 15 of the responders explicitly stated that they felt it was appropriate for *Spectrum* to address such issues, and said that they looked forward to more articles on related topics. One reader, George D. Hathaway of Toronto, went so far as to claim that the piece was "...the most important article yet published in *Spectrum*...."

Eleanor V. Goodall of Enschede, the Netherlands, was happy that the IEEE chose to publish the article. "Those who are familiar with the possibilities and limitations of technology must not only share their knowledge but also educate themselves about other, nontechnological, approaches to solving the problem of diminishing resources," she said.

On the other side of the fence, Douglas J. Hackenbruch of Trinity, NC, urged us to stick to engineering. "You only have so much energy and talent. Don't waste it on the unscientific social sciences," he said.

Bertil Ohlsson of Västerås, Sweden, found it "...difficult *not* to agree with his [Larsen's] analysis...but I still cannot support his view that IEEE should become what he calls 'a partner in leadership.' The reason is simply that this would transform IEEE into a sort of transnational political party." To do so, Ohlsson felt, would be to jeopardize the Institute's position as a "respected organization and a powerful base for promoting an understanding of technology."

Virgil I. Johannes of Holmdel, NJ, went further and protested "formally and forcefully" against the article. He felt that, since *Spectrum* published it, "...I think you have an obligation to solicit and publish an equal length article...presenting the case for economic growth, human resourcefulness, the market system, and freedom." We agree, and hope to publish such an article in the near future.

MARKET FORCES. So much for counting noses. What were some of the substantive points made by our correspondents? On the con side, the most common comment was a statement of belief that the operation of the marketplace would deal with matters adequately. As W. Alan Burris of Pittsford, NY, put it, "[Julian] Simon points out that if natural resources are becoming scarcer, then resource prices such as the price per pound of copper, should be rising in constant dollars. Yet for decades and centuries, the prices of natural resources have declined, and known reserves have increased. Known reserves of fossil fuels are sufficient for hundreds of years at present rates of consumption, and discovery and extraction methods are constantly improved. And there seems to be an unlimited supply of Malthusian-type doomsday prophets."

Stephen Fleming of Franklin, TN, would agree. He found Larsen's piece "so incredibly shortsighted as to stagger belief." Its main thesis—that one man's gain is another's loss—he called "demonstrably false." In support of his position, he said, "After the Arab oil crunch, we were told that we had as little as 50 years of petroleum left; today, we have 500 years of proven reserves."

> *'In the most important article yet published in* Spectrum*..., Raymond Larsen alerts us to the coming resource crises...'*

POPULATION PROBLEM. Among those who agreed with Larsen, the most common feeling expressed was gratitude for broaching the subject and opening it up for debate. Dave Collins of Pleasantville, NY, for example, said that "As an IEEE member, I am proud of you for stepping up to the challenge of addressing these critical issues, and I hope to see more on this in future issues of *Spectrum*." But he felt that the article had one serious omission: "[Larsen] does not even mention the engine that is driving the need for unlimited growth: unlimited population growth. As long as there is no accepted cap on world population, there can be no cap on resource utilization."

Collins was not alone in his assessment. Emil C. Evancich of Carmel, IN, considered overpopulation to be "the most serious problem the world faces." And P. Paxton Marshall of Charlottesville, VA, opined, "He [Larsen] may not be right on every point, but bold and even speculative assertions are needed to counteract the conspiracy of silence on long-term resource and population issues."

Some who agreed with Larsen's statement of the problem considered that he nevertheless had too pessimistic an outlook. Others found him too optimistic. Sid Deutsch of Tampa, FL, for example, doubts that Americans have the will to change their wasteful ways.

"Regretfully, I for one do not believe that people will pay much attention to Larsen and the other prophets of doom," Deutsch wrote. "Anybody who travels knows that gasoline abroad typically costs $4 a gallon, while in the United States we pay close to $1 a gallon, yet it is political suicide to vote for a substantial gasoline tax increase.... 'Tis the nature of the beast to drink and be merry, without an effective global plan for the future because, in the end, it will all be gone anyway when the sun blows up."

James Mathieu of Danvers, MA, who considers Larsen's article "a religious attempt to influence technology," would seem to agree. He believes that "mankind does not have either the capacity or will to save the earth's natural resources."

Several readers wrote in with detailed—sometimes exceedingly detailed—plans for solving the resource problem. David R. Criswell of Houston, TX, for example, told us about a lunar solar power system in which sunlight impinging on the moon would be converted to microwaves and then beamed to earth.

At another technological extreme, Tan Kuan Soon of Singapore sent in a very detailed analysis of a scheme in which electricity would be generated by animal power. The plan, which would be most appropriate in third-world countries, has the advantage of raising food and producing power at the same time.

Such plans deserve more space than we are able to give them in this follow-up arti-

cle; we hope to treat them at greater length in the future.

R.S. Larsen responds: I can understand why members who expect only technical and engineering topics to be covered in *Spectrum* reacted negatively to one that cannot be considered with scientific rigor. But I believe that bringing up the issues—even if my arguments were imperfect—was valuable.

The main questions I wanted to open for discussion were whether there are inherent natural limits to economic growth, and whether the IEEE should be more active in looking at how its technology affects those limitations. That said, let me respond briefly to some of the readers who disagreed with me.

Stephen Fleming simply states that everything I say is wrong, everybody knows it except me, and we have gone from a 50-year to a 500-year oil reserve since the 1973 oil crisis. I don't know where he found those figures, but they do not tally with any I have seen. For example, a recent study by the World Energy Council, a non-governmental organization representing more than 100 countries, said that reserves of oil and gas will start to run dry by the middle of the next century, according to the *Financial Times* of Sept. 15, 1993.

'Raymond Larsen's article in the July issue is so incredibly shortsighted as to stagger belief'

Furthermore, the World Bank's *World Development Report 1992* concludes that "All told, fossil fuel resources are probably sufficient to meet world energy demands for the next century, perhaps longer." Since more than half of those fossil fuel resources are coal, the two reports appear to be in substantial agreement: the world of today has about a 50-year reserve of oil and gas.

And finally, John G. Clark, in his book *The Political Economy of World Energy*, states that oil consumption from 1973 through 1987 averaged about 2.8 teragrams annually (Table 7.4, p. 246). After the considerable additional exploration that followed the 1973 crisis, total global reserves were estimated (in 1986) to be 100 Tg—less than a 50-year supply (p. 323). All the new discoveries made between 1973 and 1986 increased the world supply by only 5–10 percent. Moreover, the new oil will cost more to produce because it is located in more hostile areas.

Fleming has a simple solution—find more of everything, in outer space if necessary. The question he fails to consider is: will the growing world economy and an increasing global population force a crisis before this becomes feasible? Contrary to Fleming's belief, world hunger is not just the occasional famines we read about in our newspapers, but a much more insidious and pervasive problem.

Marvin King and W. Alan Burris state that if materials are or come to be in short supply, prices will be bid up, and we will be motivated to find substitutes. That is what I thought was supposed to happen, too. But when it comes to oil, things clearly do not work that way, and that is what worries me.

To quote Clark again, "During the course of my research, I learned that political explanations are more useful than economic in understanding energy transactions. Prices of energy are constantly manipulated by companies and/or governments to achieve institutional goals, and have little to do with the actual cost of anything." He cites the 1989 Exxon Valdez affair, which affected only Exxon's supplies—and those only marginally—but became the excuse for all companies to raise oil prices all over the United States. Later that month, "...Exxon blamed American motorists and [OPEC] for the sudden rise in price."

It does not necessarily follow, as my critics seem to believe, that since prices have not been bid up, resources are not in danger. At least in the critical case of fossil fuel energy, this view can be challenged.

James O. Hill wonders at my lukewarm support of nuclear energy. I believe that increased nuclear energy generation will be needed and there are signs it is already taking place. Hill makes a valid point that nuclear power generation has been held to a higher standard of waste management than other industries, but that, of course, is for good reason.

James Brandt accuses me of misappropriating Lester Thurow. I cited Thurow not to support my theories, but because he discusses an aspect of zero sum—that of the distribution of wealth at a given point in time. Clearly, economies have grown, and equally clearly, the cost of raw ingredients is a minor part of the equation, with the one important exception of energy. My contention is that growth will continue as long as we remain able to fuel it. At some point it will level off and then decline as competition for energy and global population growth combine to increase the pressure on the nonrenewables. I cited Thurow because he has written well about many of the same issues that concern me. *[Editor's note: Thurow was given an opportunity to review Larsen's manuscript, but declined, explaining that he was too busy to do so.]*

Richard Plourde believes that none of these problems will become an issue for

millions of years. I would be most delighted if that were true. Plourde thinks I am advocating a regimented approach to problem solving. I am not. But neither do I have a blind faith that all will be well by and by.

In November 1992, a group of 1575 scientists, including 99 Nobel laureates, issued the statement, "World Scientists Warning to Humanity," which addressed a wide range of issues, including the environment, energy, global population growth, poverty, women's equality, and war. "No more than a few decades remain before the chance to avert the threats we now confront will be lost and the prospects for humanity immeasurably diminished....Pressures from unrestrained population growth...can overwhelm any efforts to achieve a sustainable future."

Henry Kendall, chairman of the Union of Concerned Scientists, noted that "This kind of consensus is truly unprecedented. There is an exceptional degree of agreement within the international scientific community that natural systems can no longer absorb the burden of current human practices" (AP, Nov. 18, 1992).

Claude L. Emmerich believes that recycling will solve all problems. I agree that recycling can solve many problems, and is a key to future sustainability. But some things—oil, for example—really do get used up, once and for all. And having unlimited energy in the universe is very different from being able to tap into it at an acceptable cost and risk. Nuclear energy, for example, may prove to be too expensive, too risky, or quite possibly both.

Finally, Douglas J. Hackenbruch advocates that the IEEE keep its nose to the grindstone of technology and leave these issues to nonscientists. To whom, I would ask? To politicians, most of whom are trained as attorneys, and whose overwhelming agenda is to be re-elected? To economists, who rarely agree with each other, and whose record leaves much to be desired? To corporate leaders, who seem obsessed with the short-term goal of returning "bottom-line" results, and who increasingly view employees as a commodity to be exploited and then disposed of?

If we do not cultivate a healthy dissatisfaction with the status quo, we will go nowhere. Some say we should become involved with the issues, but only as individuals. I disagree. The responses to this article have shown enormous disagreement on such basic facts as the extent of global oil reserves. If we speak out individually without first resolving such basic discrepancies among ourselves, we will only cause more confusion. A planned effort, intended not to introduce regimented thinking but to establish a body of facts that we all can share, is what I advocate.

Michael J. Riezenman Senior Editor

Reflections

Technology isn't the problem

Maybe I'm going to the wrong meetings these days. I often think that the *good* meetings—where important technical issues are debated with courtesy and keen philosophical insight—must be somewhere else. I suspect that they are being held on weekends or while I am on vacation. Or perhaps I'm on a secret list of people not to be invited to these rewarding occasions. I usually go to the other kind.

For whatever reason, in recent months I have attended a number of unconnected meetings that seem to share a certain theme. No matter what the meeting is about, at some critical time early in the discussion, someone says flatly, "Technology isn't the problem."

This provocative phrase is uttered in an authoritative voice and followed by a brief silence filled with a lot of synchronized head-nodding. Everyone agrees. Having dismissed technology, attendees then move on to the really important issues, those that involve marketing, political, legal, economic, or business factors. I have never, for example, heard anyone say that business issues are not the problem.

At the word "technology," an important-looking executive turns to his assistant and asks, "Technology? ...Isn't that the stuff we already have enough of?"

"Right, J.P.," affirms the assistant, visibly impressed with the clear thinking of upper management.

The executive straightens his back and tugs emphatically at his vest. If this were a comic strip with a balloon above his head representing his thoughts, it would read: "What's important is wheeling and dealing, which I'm good at. It has nothing to do with technology, which I don't understand.... Of course, I could understand it if I really wanted to, but fortunately it's not important in these real-world business situations."

To be honest, at a recent meeting I even heard myself saying that technology was not the problem. My reaction to my own statement was similar to something that once happened to my dog. It was sleeping on the rug at my feet while I quietly read a book, and must have been having a doggy dream, because out of nowhere it barked in its sleep. Awakened instantly, it leaped into the air and looked frantically around the room. "Who barked?" its startled expression said. "Where is this other dog!?" That was sort of my response, too, after hearing my own dismissal of technology.

If this "technology isn't the problem" attitude is becoming widespread, it's probably our own fault. We engineers have done our job too well. We've provided too many transistors, too many PCs, too many MIPS, too much shrink-wrapped software, and too many bits per second—more than anyone can use just yet. The feeling that hangs in the air is that we need a chance to exploit what we already have—to catch our technological breath, as it were.

Perhaps there is an embarrassment of riches here. Technology makes all things possible. Some business people believe that technology has presented too many alternatives, without differentiating among approaches. With a figurative sweep of an arm, the business executive alludes to the vast panoply of technological capability. What really matters, he says, is how you market this stuff, what investment strategy you pursue, what national policies are adopted, how clever your intellectual-property lawyers are, and so on. Technology isn't the problem; we already have enough.

I have been hearing these refrains enough lately, and they always depress me. All this technological capability has resulted in a marvelous business turmoil. It is a seething pot of magic potential. We engineers are the cooks, and we possess the modern "eye of newt" in our ICs, software, and communications tools. I hate to see that talent go unappreciated.

I can only fantasize about how technology might be elevated in importance. In my imagination, I have a plan. After all, if we giveth, then we can taketh away. So let's give the world less technology. Let's take some of these alternatives off the table.

Suppose, for example, that Intel was to announce new versions of its microprocessors that featured lower clock rates. Instead of superseding the 80486 with the 80586, the company might unveil an 80485 with less capability. To compensate for the diminished power, this model would be more expensive.

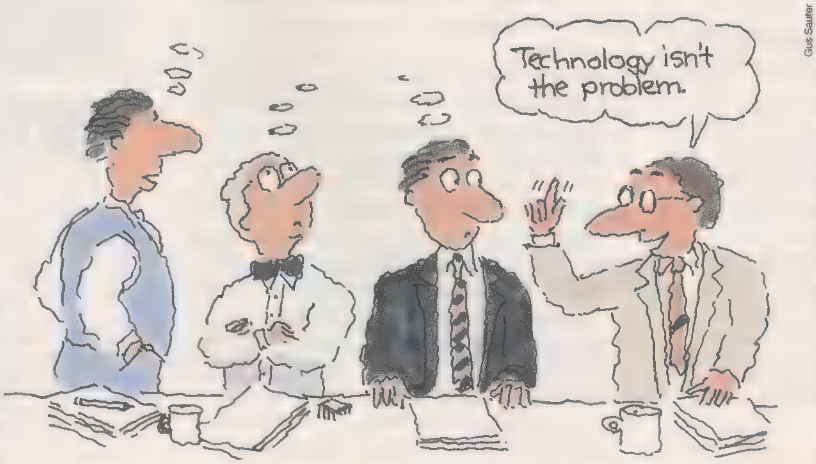
These commercial developments could be accompanied by theoretical work showing new versions of the Moore chart in which transistors' sizes begin increasing with time. We could blame this turnaround on metallurgical or chemical effects leading to electromigration of microstructure conductors. EEs would be blameless, and no one would understand.

Alternatively, we could allude to global warming, the depletion of the ozone layer, or the ubiquity of high-tension power lines. Maybe we could blame fluorescent lights or cholesterol. Then the public would understand completely; they know the world is spiraling out of control. Why should electronics be the exception?

Microsoft would have to do its part, too. Windows NT would be supplanted by Windows 2.9, followed by version 2.8, and so forth, skipping over numbers used in earlier releases. Successive versions would include less functionality and be increasingly inefficient at higher prices, while the user interface would become more obscure. This overall regression would be explained as an outgrowth of chaos theory, or related in some way to the savings and loan fiasco.

Before long, business meetings would acquire a different flavor. At the mention of the word "technology," the executive might look up from his notepad and ask, "Technology?... Isn't that the stuff we don't have enough of?" The assistant might quietly chew his lip in an effort to project an attitude of profound concern.

The thought balloon above the executive's head would read: "I wish I understood this stuff."

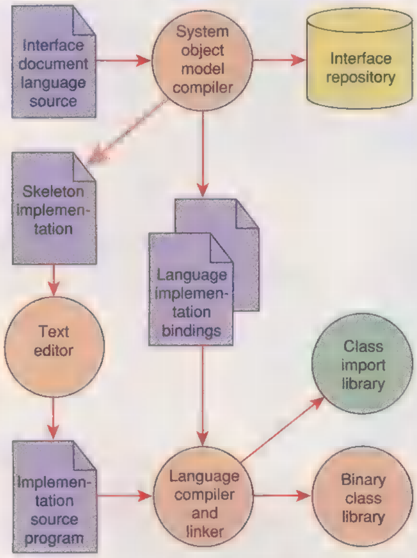


Robert W. Lucky

Program notes

SOM ware beyond the C

Advocates of object-oriented programming (OOP) claim that languages like C++ or Small Talk can make programmers decidedly more productive. But with OOP, an application can be moved only after complete reworking if the particular OOP library it uses is unavailable with a new compiler, platform, or language. So using OOP can also hamper application portability.



With IBM's System Object Model (SOM), a programmer creates a new class library by first describing its interface in a source file. This the SOM compiler converts into a source-code skeleton implementation and some object-code linkage implementation bindings. (It also deposits an entry describing the interface to SOM-compliant compilers into the interface repository.) With a text editor, the programmer fleshes out the skeleton into complete native source code for the class. Finally, a language compiler and linker converts the source code into object code and links it with the object-code bindings, to build a binary, SOM-compliant, class library.

So serious is the problem of incompatible objects that over 300 companies have formed a consortium, called the Object Management Group (OMG), whose purpose is to develop standards for object technologies. One of OMG's first standards is a common object interface called Common Object Request Broker Architecture (Corba). A commercial implementation of this, called System Object Model (SOM), has been created by IBM Object Technology Products in Austin, TX.

The company has shipped SOM tools for C and C++ compilers with the OS/2.2 operating systems. SOM itself is a single binary object model with a common calling convention that can be used by all programming languages. The SOM tools—implemented with a run-time dynamic link library (DLL), an interface document language compiler (IDLC), and a set of class libraries and definitions on OS/2—serve as a preprocessor for standard language compilers [see figure, at left].

For OOP developers, SOM could open up new markets: a SOM-compliant binary library can be used by any SOM-compatible compiler for any language. To help this process along, IBM has released an upgraded set of stand-alone tools, the SOM Objects Developer Tool Kit, which extends an existing compiler to comply with SOM.

Today, IBM's SOM tools are the only way a developer can create binary class libraries. However, MetaWare Inc., the developer of multiplatform C/C++ compilers, is working on a technique called DirectToSOM for a future version of High C/C++. It will allow developers to create, read, and derive SOM-compatible object modules without the IBM tools.

Being applicable to all operating systems and all compilers, SOM is ground-breaking technology for OOP. Unfortunately, IBM is being lackadaisical about marketing it. Calls to IBM Object Technologies Products to discuss SOM for this column were not returned. When, through sheer persistence, I finally got in touch with one of the SOM developers, our one-minute conversation ended when the developer said, "No one here has time to talk to anyone about this product." *Contacts: for SOM, IBM Developer Relations, 1400 Burnet Rd., Austin, TX 78758; 512-823-0000; or* **circle 100**; *for the High C/C++ compiler, Kevin Grimes, MetaWare Inc., 2161 Delaware Ave., Santa Cruz, CA 95060-5706; 408-429-6382; or* **circle 101**.

Making applications Notes-worthy

Windows application developers can convert stand-alone programs into groupware running under Lotus Notes with the aid of a new technique from Lotus. Application Field Exchange, as it is called, is essentially a rule for reading and writing information stored in the Notes database. With it, Notes and Notes-aware applications can tell each other what they have done to a document.

Notes stores documents as records in a database. Each record contains fields of various types. Some fields may contain information describing the document using Microsoft's Rich Text Format (RTF).

One field used by the protocol contains an object created with a stand-alone application and embedded with Windows' Object Linking and Embedding (OLE) mechanism. When a user running Notes selects a document, Notes identifies the application that created the embedded object and checks Windows' OLE registry to see if the application supports Application Field Exchange. If it does, Notes launches the application as an OLE server.

Then Notes uses the Exchange technique to send it information about the document, such as its "handle" and the security privileges the application must have to be allowed to manipulate the document. The application can then exchange information directly with any field in the Notes document using the Notes Applications Programming Interface (API).

Freelance Graphics 2.01, Ami Pro 3.01, and Improv 2.01 (all released this past summer) are the first products equipped with Application Field Exchange. To promote this technique (and Notes), Lotus is distributing a free Application Field Exchange–smart database for storing Freelance Graphics presentations in Notes. *Contact: Lotus Developer Relations, Lotus Inc., 55 Cambridge Parkway, Cambridge, MA 02139-1901; 800-DEVRELS; or* **circle 102.**

Help from Cyberspace.

Fortune magazine recently contained an article on the Internet and the growth of information technology ("Boom Time on the New Frontier," in the Autumn 1993 supplement). A graph in the article demonstrated that "everybody" who has a computer is connected to "everybody": almost 1 800 000 hosts were on the Internet as of July 1993.

Many software developers are latching onto Internet's widespread availability, using it to provide technical support. Microsoft is the latest company to jump into Cyberspace. Developers can use anonymous ftp to access Microsoft's Knowledge Base and Software Library through an ftp server, ftp.microsoft.com, with IP address 131.107.1.11. The password is your Internet name. *Contact: Microsoft Support Network, Microsoft Corp., One Microsoft Way, Redmond, WA 98052-6399; 800-936-3500; or* **circle 103**.

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Spectral lines

NOVEMBER 1993 Volume 30 Number 11

The challenge of change

Like horse-racing fans engaged in serious study of *The Daily Racing Form*'s handicapping charts, every month under- and unemployed engineers pore over the classified employment ads in *IEEE Spectrum*. Often, their aim is to switch to a career path outside those mainly defense-related areas of technology now stalled indefinitely. Fortunately, engineering is a problem-solving profession, and opportunities are emerging in young and vigorous new technologies. Let's look at a few.

- **Client/server computing.** The bulk of the results of the word processing done at *Spectrum* is handled not by the hard drive of Apple Macintosh Centris PCs (like the one on which this column is being written), but on a somewhat larger unit known as a server. Almost a half million servers were sold in the United States last year, representing a market of almost US $4 billion. Client/server computing, the hottest area in network computing, covers everything from remote file systems to complex database inquiries. A server with just 80 megabytes of main memory and two processors can cope with 172 transactions per second from as many as 1740 desktop PCs. All this, of course, leads up to the need for the speed of the well-publicized Data Superhighway (which some would argue is already here and called Internet).
- **'Green' product growth.** Recently, an engineer friend noted, "The environmentalists have won. To some extent we—engineers—have all become environmentalists." While "green," or environmentally friendly, products are primarily a social benefit, new legislation in Europe and the United States is demanding a keener environmental awareness in product design, and hence creating new openings for engineers.

Even the common refrigerator is affected. In July, Whirlpool Corp., of Benton Harbor, MI, won a $30 million prize from a coalition of U.S. electric utilities for a prototype refrigerator that runs 25–50 percent more efficiently than current models do. No chlorofluorocarbons (CFCs) are used in the design, which also employs improved compressor motors and more efficient insulation.

- **Real pie in the sky.** Over and above the $9 billion space station effort, which will bring together technical resources from the United States and Russia, commercial space ventures are becoming a big business in their own right. In the United States alone, they generated $5 billion in revenues last year, of which about $4.3 billion came from commercial satellites and satellite services and $200 million came from remote sensing data about the earth from space.

The concept of wireless global voice communications once elicited mostly polite disclaimers of interest from industry and governments. Not any more. Motorola Inc.'s Iridium project, which will use 66 satellites for a service connecting callers anywhere in the world, may prove too expensive in its first iteration for consumers; but it could find a ready market among international business travelers.

To launch the Iridium satellites 9000 to 10 000 km into their near-earth orbits, Motorola proposes to use McDonnell Douglas Delta rockets, Proton rockets from Russia, and China's Long March boosters. The first satellites are scheduled to be launched in 1996, with Iridium service to begin in 1998.

- **'Have phone, will travel.'** The worldwide explosion of interest in voice and data communications is manifest in the huge new demand for cellular telephones and pagers. A recent report on mobile communications in London's *Financial Times* put the number of cellular subscribers in Western Europe at 7 million as of July. Last year the total was 5.2 million. The first digital cellular networks in Europe, called Groupes Spéciales Mobiles, were launched last summer.

In North America, through use of high-speed signaling systems that track a cellular user's whereabouts and redirect calls to his or her phone anywhere on the continent, the long-awaited seamless cellular network is now almost literally at hand. While a call is going out, the cellular phone sends signals to the local wireless network identifying itself by number. Any calls coming in to that number are then automatically routed within the nationwide system to the local wireless carrier, if necessary by the regular long-distance telephone network, for transmission to the roving cellular phone.

Currently, the United States has 11 million cellular subscribers. By the year 2005, there will be 60 million customers for personal communications services, according to an estimate by Arthur D. Little Inc., the Cambridge, MA, consulting firm. In the meantime, U.S. cellular suppliers are working on digital cellular technology, which will add to system capacity.

The Pacific Rim also is in the midst of a cellular phone boom. The *Financial Times* reported that the area's 12 largest markets had more than 4 million subscribers by the end of 1992, a number that will possibly double by the end of this year. The pager population in this region is still larger, over 10 million units strong, according to industry estimates, with more than 6 million in Japan alone. Pagers have even caught on in a big way in China, with sales this year expected to top 3 million.

Hard on the heels of the cellular revolution come the less costly personal communications network (PCN) services. These digital mobile phone services are aimed at larger metropolitan areas. Industry analysts estimate that PCN systems may absorb 10 times as many customers as an equivalent cellular network. In Britain, a high-capacity derivative of the Groupe Spéciale Mobile, operating at 1800 MHz, should enable companies in this field to keep call charges more in line with those of conventional wired phone networks.

- **Personal digital assistant (PDA).** Industry wags have said that the PDA business is a zero billion dollar business, but these devices soon will be capable of facsimile, radio, infrared, voice, and electronic-mail communications over cellular, noncellular, or hard-wired connections.

Apple Computer Inc.'s Newton MessagePad is in the first wave of these products. Slightly bigger than a paperback novel, it weighs about 0.4 kg, has a 7.5-by-10-cm screen, and uses a pen-based operating system. It even has a built-in ability to learn its owner's habits, from most favored restaurants to the preferred format for business letters.

Enough. I could go on and on. But I'm sure you get the point: if you're all revved up for a new challenge but none of the usual options beckons, stifle your prejudice against the unknown and try to get involved in something new. Good luck, and good hunting.

Murray Slovick

The flat panel's future

Notebook PCs and wall-mounted, high-definition TVs define the fast-changing world in which display makers must survive

The Japanese giants of the flat-panel display industry—Sharp, NEC, DTI (a Toshiba-IBM joint venture), Hitachi, and Hosiden—have spent an estimated US $3 billion to commercialize the color, active-matrix liquid-crystal display. Now that heavy investment is starting to pay off.

Less than three years ago, manufacturing yields of color liquid-crystal displays (LCDs) based on active-matrix technology were a dismal 10–20 percent for most manufacturers. Today, the leaders among them are—with evident satisfaction—claiming yields in excess of 50 percent. As a result, prices are down (a little) and, according to industry consultant Larry Tannas, chairman of the Japan Technology Evaluation Committee (JTEC) on display technology, Video Graphics Adapter (VGA) versions of these displays are being delivered this year. With additional manufacturing capacity now going on line, next year an estimated 500 000 displays will be produced each month, Tannas said. But even with this additional output, supply is not expected to catch up with demand until 1996.

The image quality on the best displays is stunning [Fig. 1]. Sizes also are inching up. Prices, though, are still too high for color active-matrix LCDs (commonly called AMLCDs) to be a truly mass-market item. After all, how many $4000 laptop computers will people buy?

Prices will drop, but the long-predicted target year of 1995 will not see a color VGA AMLCD priced at ¥50 000 (or US $500 at a projected ¥100 to the dollar). A more realistic estimate is 1996 or 1997, said Hosiden Corp.'s Shinji Morozumi, developer of the AMLCD TV receiver, when he spoke in Seattle last May at SID '93—the annual Society for Information Display's International Symposium and Exhibition.

With all of this, the Japanese giants and their North American marketing groups seem generally optimistic, but new technologies—such as the active-addressing display from Motif Inc., Wilsonville, OR, or the plasma-addressed unit from Tektronix Inc., Beaverton, OR—threaten to cloud at least a portion of active matrix's rising sun.

Kenneth I. Werner Contributing Editor

PASSIVE PROBLEMS. AMLCDs are complex, but the complexity is there for good reason. In the simpler, passive LCDs like the supertwisted nematic (STN) units used in most monochrome notebook computers [Fig. 2], a tradeoff limits display performance. Because the rows in such displays are addressed sequentially, the number of rows of pixels in the display must be traded off against the length of time during a frame period that the driving circuitry can apply voltage to a turned-on pixel.

For instance, if there are 240 rows, any pixel that is turned on during that frame period can only have its on-voltage applied to it for approximately 1/240 of the frame period—which is generally 1/60 second. This time division of voltage is called multiplexing, and the portion of the frame period that each on-pixel experiences the voltage is called the duty cycle.

Thus, any pixel in a 240-row display would have a maximum duty cycle of 1/240. All other things being equal, the smaller the duty cycle, the poorer the contrast ratio, the narrower the viewing angle, and the fewer the gray levels.

Another potential problem with passive display designs is crosstalk. In display technology, crosstalk is the tendency for pixel intensities in a column containing both on- and off-pixels to vary around their intended values. Modern displays exhibit crosstalk to varying degrees. It is particularly noticeable in a windowed environment where, for example, the vertical edges of a dialog box may have a ghostly continuation beyond the box's horizontal edges.

To avoid flicker in passive displays, a relatively viscous and slow-to-respond liquid-crystal material must be used. This solves the flicker problem but prevents the display from responding quickly enough to reproduce video signals or allow a mouse cursor to be moved rapidly across the screen without submarining—temporarily disappearing as it is moved.

A pixel turn-on time, T_{on}, of 125 ms is on the borderline for keeping moving mouse cursors visible and, for video, 50 ms is needed. Some of the latest passive displays appearing in laptop computers exhibit a T_{on} in the vicinity of 125 ms. (T_{on} is commonly referred to as one-way optical response time. Two-way response time, $T_{on} + T_{off}$, is also a frequently cited specification. It is approximately double the one-way response in most displays.)

Active-matrix LCDs were developed to overcome these limitations of passive displays. In the early 1970s Peter Brody and his group at Westinghouse Corp., Pittsburgh, recognized that placing a switch at each pixel location was one way of avoiding crosstalk and optical response tradeoffs forced by time-multiplexing the driving signals. The Westinghouse group employed a transistor fabricated with thin films of semiconducting material.

ACTIVE DEVELOPMENT. Researchers experimented with cadmium selenide and other materials. But since the quality of this thin-film transistor did not have to be very high, by the early 1980s most developers had settled on amorphous silicon as a good compromise between adequate performance and an economical, low-temperature manufacturing processing.

But a color VGA display contains 640-by-480 full-color pixels, and each full-color pixel in most designs contains a red, a green, and a blue subpixel. (Some older designs add a fourth, either white or green; at least one manufacturer stacks three panels and uses subtractive primaries to obtain colors by subtraction.) Since each AMLCD subpixel requires a transistor, a 640-by-480-pixel display that uses three subpixels for each color pixel requires over 920 000 transistors, which must be deposited on one 9- or 10-inch substrate. With a few minor exceptions, all these transistors have to work.

The problem has been likened to making perfect 10-inch ICs with 3-μm design rules at high yield. Its solution has proved far harder and costlier than anyone foresaw. Some analysts say that the $3 billion invested to date will never be recovered using

Defining terms

Liquid-crystal display (LCD): a display in which the opacity of a gelatinous quasi-crystalline material is controlled by an electric field.

Optical response time: the amount of time it takes for an LCD pixel to change opacity.

Pixel duty cycle: the portion of the entire display cycle during which an address signal is applied to a single pixel to turn it on.

Transmittance: the amount of light able to pass through a material, given as a percentage of the light entering it.

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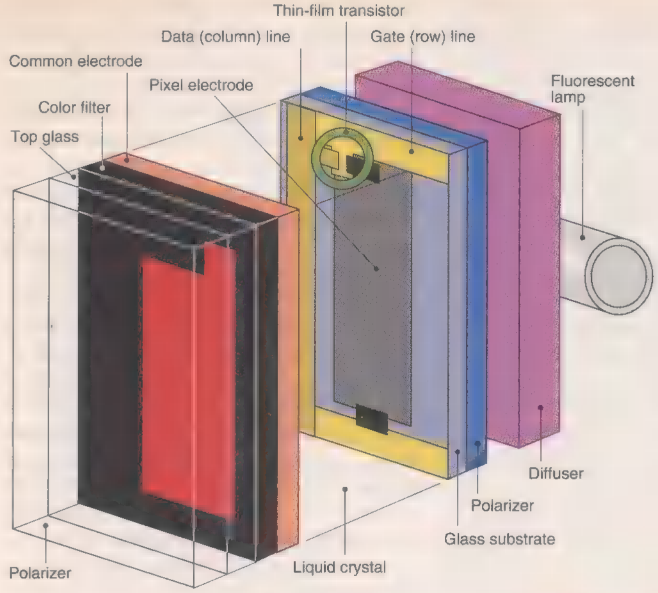
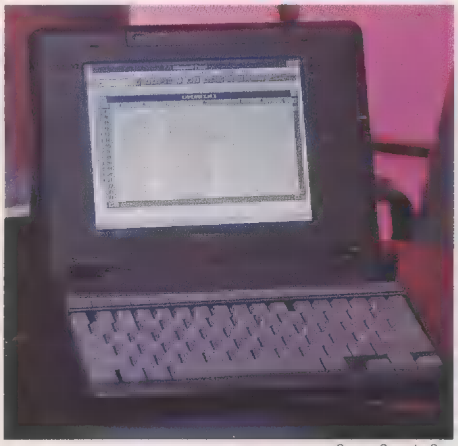
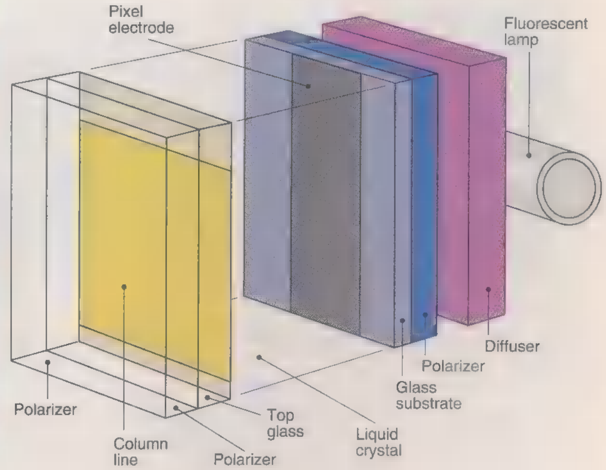


[1] Among the most sophisticated commercial color liquid-crystal displays (LCDs), Sharp Microelectronics Corp.'s 10.4-inch active-matrix LCD display [above] exhibits thousands of colors. Like other top-of-the-line displays, it is based on thin-film transistor technology [left].

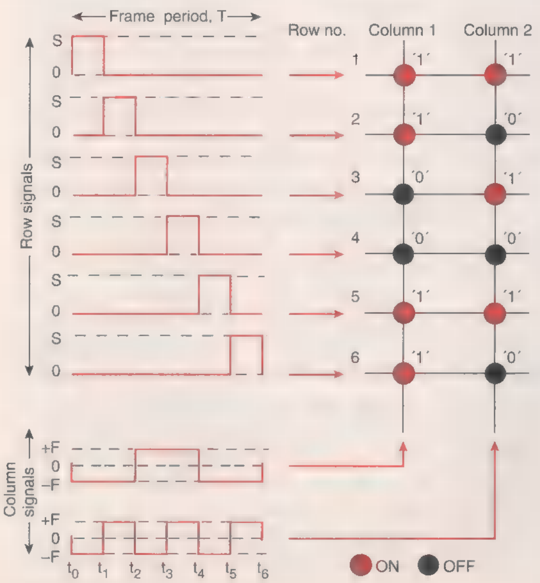
[2] Passive LCD technology [far right] is simpler than active-matrix. The pixel count, contrast ratio, response, and gray scale of top-of-the-line passive LCDs are gradually increasing to provide a crisper, more pleasing display, such as that used in Compaq Computer Corp.'s most recent notebook computer [right].

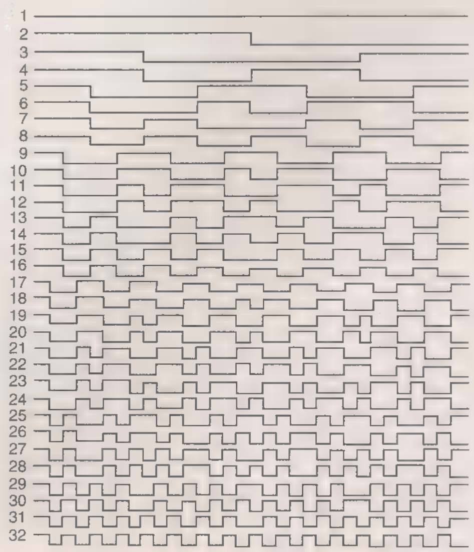


Compaq Computer Corp.



[3] In a traditional passive-matrix liquid-crystal display, a pixel is turned on by an "on" column signal during the time it is selected by a row pulse [left]. Each pixel experiences a voltage that is the difference between the row and column signals. F is a voltage selected to produce the desired pixel response. The column signal is set to −F to turn a pixel on, +F to turn or keep it off. (The pulse width, t, is equal to the frame period—usually about 1/60 second—divided by the number of multiplexed rows.) The column signals shown are intended to produce a binary display—one whose pixels are entirely on or entirely off—but crosstalk hampers full realization of this intention. In active addressing of a passive display, a much more complicated set of row functions [right] makes it possible to use a faster liquid-crystal material, retain a flicker-free display, and eliminate crosstalk. Any set of orthonormal functions will work, but the approach requires the column voltage to be a function of every pixel in the column. Walsh functions—the set of order 32 is shown—are a set of functions that can sharply reduce the number of computations needed to generate the column signals. (Figures courtesy of Terry Scheffer and Jürgen Nehring at Motif.)





traditional measures of cost recovery. Whether or not these costs really can be recovered, the extremely high manufacturing investment required to make AMLCDs affects both suppliers and consumers.

Only seriously committed suppliers can enter this game, and only successful ones remain in it. The price tag for the equipment in a single, state-of-the-art AMLCD production line exceeds $100 million, said consultant Tannas, and industry leaders are now adding second and third lines.

Several Japanese companies that had been actively involved in AMLCD development have decided to fold their cards. Outside Japan, only two North American companies—Optical Imaging Systems (OIS), Troy, MI, and Litton Canada, Toronto—are making the displays, and only one new player, a consortium led by Philips Electronics NV, Eindhoven, the Netherlands, has summoned the courage to build a full plant for active-matrix LCD manufacturing.

For consumers, the price of color VGA AMLCDs cannot drop sharply before the second half of this decade, even if yields rise to 70 or 80 percent, because manufacturers need to recover the cost of building the plants scheduled to go on line next year.

Given the continuing prospects for high AMLCD prices, therefore, could there be a window of opportunity here for other technologies? In fact, there are at least two, and they are related by their reliance on the innovative use of factory-proven approaches.

The most recent alternative cropped up in 1992, when Terry Scheffer and his colleagues at In Focus Systems announced a new method for driving passive LCDs that would give them most of the benefits of active-matrix displays.

Traditionally, in both active and passive displays, the display signal is applied to the columns of pixels in parallel while the rows are pulsed sequentially. Each pixel is exposed to a potential that is the difference between its row and column signals. When an "on" column signal and a row pulse simultaneously excite a pixel, the resulting potential difference is sufficient to turn it on [Fig. 3, left]. Unfortunately, for passive LCDs, the technique also produces intermediate voltages that engender crosstalk, as previously noted.

In STN displays, gray levels are implemented with two techniques. Frame modulation applies pixel select and nonselect voltages to a pixel in each frame over a cycle of, say, 16 frames. The response time of the LCD (about 150 ms) is usually much longer than the frame period (about 17 ms), so the rms average of the 16 different voltages produces a shade of gray—a gray level—that is between the pixel's fully on- and fully off-state.

Alternatively, simple pulse-width modulation can be used. Here, the column signal is held low for a portion of the select interval and then high for the remainder of the interval. The resulting rms voltage again produces a particular gray level, since the transmittance of each LCD pixel is proportional to the rms value of the voltage applied to it.

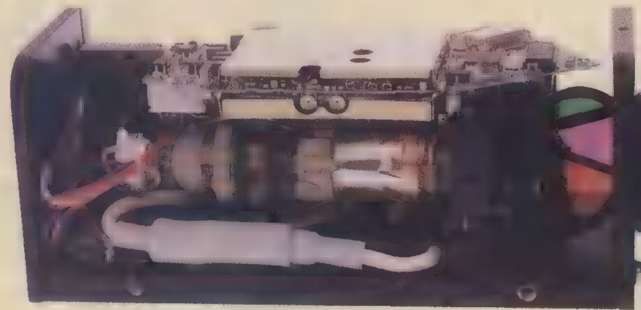
The contrast and viewing angles of STN displays are now quite good, but response times remain much too long for video. The problem is not that liquid-crystal materials are inherently slow. Higher-voltage and lower-viscosity liquid-crystal materials easily accommodate video rates in active-matrix displays.

Using a fast-responding, high-voltage liquid crystal in passive STN displays, however, results in the liquid crystal's state decaying markedly between select pulses. The display is no longer responding to the rms voltage averaged over a frame period, but is responding to voltage changes during the frame period. The result is reduced transmittance (brightness), poor contrast, and a narrower viewing angle.

The In Focus team realized (and have demonstrated) that it is possible to use a faster liquid-crystal material, have a bright flicker-free display, and minimize ghosting effects, all at the same time. They do it by employing a much more complicated set of row functions [Fig. 3, right] to distribute the selection intervals over the frame period, and by combining the row functions with more complex, calculated column functions.

The tradeoff is that the row functions are not only more complicated in themselves,

Return of the color wheel



Thomas Electronics Inc.

The original system proposed for color television in 1940 was an electromechanical color-wheel system. Frames for the red, green, and blue components of the color image followed each other sequentially on a black-and-white TV screen. A motor-driven wheel containing red, green, and blue gels rotated in synchronization with the frame presentation, and the viewer observed the screen through this rapidly rotating color wheel. A full-color image emerged as the viewer's visual system blended these sequential frames. The general term for such systems is frame-sequential color.

Two discouraging problems occurred with these early frame-sequential systems. First, they required a cabinet roughly twice as wide as an otherwise equivalent monochrome receiver. Second, and more seriously, they required three times the frame rate of an otherwise equivalent monochrome system. The electronics of the period could not produce a frame rate of 180 frames per second (60 frames per second times 3 color images per full-color frame), and using a reduced frame rate produced a flickering image.

With the success of RCA Corp.'s shadow-mask system, which distributed the red, green, and blue images on the tube face instead of presenting them sequentially, field-sequential color fell out of fashion. Tektronix Inc., Beaverton, OR, brought it back three years ago with its liquid-crystal color shutter. This system replaced the color wheel with a stationary, solid-state device no larger than the screen of the monochrome cathode-ray tube (CRT) it works with. The shutter is fast, but as its associated polarizers absorb a great deal of light, a fairly bright CRT is required.

What all this buys is a very-high-resolution color display. Stand-alone shutters and tubes with shutters bonded to their faceplates are currently available as off-the-shelf products under the NuColor trade name. A 9-inch NuColor monitor costs US $950.

This year at the Society for Information Display Show in Seattle, two new field-sequential color systems were exhibited—both based on electromechanical color wheels. The first was Dallas-based Texas Instruments Inc.'s projection display based on the company's digital micromirror device [see the following article, "Mirrors on a chip," by Jack M. Younse, p. 27]. The second was a miniature color-wheel CRT from Miyota, Nagano Prefecture, Japan, which is being distributed by Thomas Electronics Inc. of Wayne, NJ [see figure above]. The miniature 0.6-inch-diagonal monochrome CRT is derived from one Miyota makes for camcorder viewfinders and weighs only 5 grams without deflection coils. Complete with deflection coils, motor, and color wheel, the weight is less than 50 grams.

Because the monochrome has no shadow mask, resolution is limited only by the beam spot size and the deflection electronics. Unlike the situation in electronic color shutters, light absorption within each color band is not large, so images are bright. Initially, Miyota and Thomas are marketing the color-wheel tube as a relatively low-cost—less than $1200—alternative to Mil-Spec tubes for applications such as helmet-mounted displays. — *K.I.W.*

but also require a column voltage whose value is a function of every pixel in the column. These more complicated signals have to be calculated by more complex display electronics, but the electronics can be implemented in traditional ICs. This approach—dubbed active addressing by In Focus—allows the display manufacturer to do something very exciting: move the transistors required for active-matrix LCDs off the display glass and into plastic packages, where they can be implemented much less expensively.

What's left on the glass itself? Nothing more than is found in a conventional passive display. A more responsive liquid-crystal material is substituted for the conventional material and the cell thickness is reduced, but the manufacturing process is otherwise identical.

Can the degree of this excitement be quantified? Judging by Motorola Inc.'s August 1992 decision to invest $23 million in a joint venture with In Focus, the answer is yes. Called Motif, the venture is currently building a plant to manufacture the displays in Wilsonville, OR. Motorola, headquartered in Schaumburg, IL, will manufacture the active-addressing chips, which will be available to all display manufacturers—not just Motif—as soon as production levels permit.

Motif's manufacturing line was turned on in September, engineering evaluation units are to be shown later this month at Comdex in Las Vegas, and the company plans to ship production models early next year.

On the all-important matter of price, Scheffer, who is now chief scientist at Motif, said that the new displays, while more expensive than passive color LCDs, will be considerably less expensive than AMLCDs. The difference in price between his new display and a standard passive color display should be about one-quarter the price difference between a color AMLCD and a passive color display.

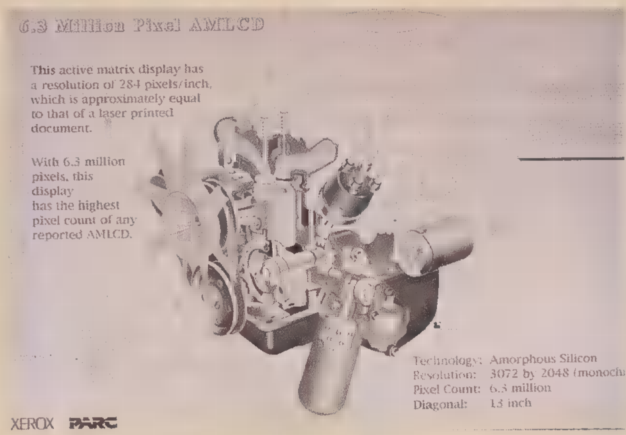
PASSIVE-MATRIX COLOR. The second alternative to color AMLCDs is the existing standard passive-matrix color LCD. Given its limitations, the fact that passive color is any kind of viable alternative to AMLCDs is something of a surprise. Three years ago, Tim Patton, marketing manager at Hitachi America Ltd.'s Electron Tube Division, Norcross, GA, predicted that, while the availability of AMLCDs increased and their prices dropped, there would be a temporary window of opportunity for passive color. Although he expected that window to last only a year or two, he proved more prescient than many of his colleagues, who did not see much of a future for passive-matrix color.

Three factors have broadened the window of opportunity spotted by Patton. Getting AMLCDs into production took longer than anticipated. Then, once display manufacturing began, delays occurred in bringing yields up to the point where original-equipment manufacturers (OEMs) could commit to using the displays in products. And, initially because of low yields, and later because of high plant investment, prices stayed—and continue to stay—high.

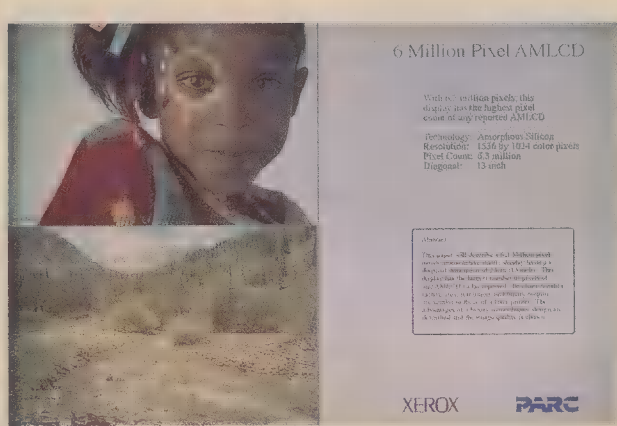
Over the last two years Patton's window has also been widened considerably by a surprising improvement in the image quality of passive color displays. Remarkable improvements in color saturation, crosstalk, and viewing angle were seen in displays from such companies as Sharp, Hitachi, and Kyocera at this year's SID. Sharp Microelectronics Corp. and Kyocera Corp. showed displays with a pixel turn-on time of roughly 125 ms, and virtually everyone else is following suit. These faster displays are eminently usable for the vast majority of common computer applications, although they do not have the optical response for animation or video.

Price and availability are the final two variables in the passive-color–display equation. Passive color displays are more expensive than monochrome because, like AMLCDs, every color pixel must contain three subpixels, each of which requires a red, green, or blue filter. The advantage of passive color displays is that they do away with all those thin-film–transistor switches at every subpixel. The result is a display that is much easier to make, so manufacturing plants require one-seventh the in-

Xerox's 6.3-million-pixel LCD



Xerox Palo Alto Research Center



A 10-inch, VGA, liquid-crystal display packs 640 by 480 pixels into an active area of approximately 20 by 15 cm, giving a linear pixel density of 80 pixels per inch (or a pixel pitch of roughly 0.32 mm). Notebook PC users have become accustomed to such a pixel density—and its limitations. They do not, for instance, even try to read the equivalent of 6-point type on such screens. But print that 6-point type on a 300 dot-per-inch (dpi) laser printer, and it is eminently readable.

Without a 300-dpi display, WYSINWYG (what you see is not what you get). There are a few, very expensive, 200- and 300-dpi monochrome cathode-ray tube (CRT) monitors around, but liquid-crystal displays (LCDs) have not come close. For this reason, Xerox Palo Alto Research Center's 13-inch-diagonal active-matrix LCD, with its 6.3 million pixels, is unique [see figure, above left].

Not only does the display have the largest number of pixels ever to appear on a single LCD, but there are 284 of them to the linear inch. The effect is startling: laser-printer quality on an LCD.

A color version has the same number of dots, with quartets of those dots in red-green-blue-green quad patterns serving as the subpixels in each full-color pixel. The result is a 1536-by-1024 full-color display [see figure, above right]. The U.S. Advanced Research Projects Agency, Arlington, VA, helped with the funding.

—K.I.W.

vestment of a color AMLCD plant, according to Hitachi's Patton.

Consequently, major display manufacturers are now quoting prices between $550 and $850 for production quantities of passive color displays, which compare with prices in the vicinity of $1400 for color AMLCDs. Furthermore, as of late summer, demand for color AMLCDs has been handily outstripping supply, so manufacturers are trying hard to convert OEM customers to passive color displays, which have been available in quantity.

Because the plant investment required for passive color displays is relatively modest, more players—including Kyocera and Optrex/Satori, Torrance, CA—can afford the ante. That bodes well for price competition and continued availability in the near term.

There is at least a chance that other existing technologies might find ingenious application to color laptop computers and other portable systems, too. For example, Miyota, Nagano Prefecture, Japan, has suggested that its new miniature color-wheel cathode-ray tube could be mounted in a laptop case and used in a projection or virtual-image configuration. The well-known custom and semicustom cathode-ray tube manufacturer, Thomas Electronics Inc. of Wayne, NJ, has agreed to distribute the small, lightweight tube for Miyota [see "Return of the color wheel," p. 20].

The development of color LCDs is a glamorous activity at the moment, but monochrome STN LCDs are the industry's bread and butter. VGA panels of excellent quality are readily available from many sources for around $200.

IN BLACK AND WHITE. Film compensation, which has replaced heavier and more complicated dual-cell compensation techniques, produces true black-and-white displays and all but eliminates color distortion. In the best displays, contrast ratio, viewing angle, and crosstalk are at very acceptable levels, while white backgrounds are admirably free of blotchiness and backlights produce acceptably bright images with reasonably even illumination. Displays routinely offer 16 levels of gray, and 64 levels are no longer unusual. In some, response time is approaching 125 ms.

However, all of these characteristics can vary widely among the displays in current laptop computers and, to a somewhat lesser extent, among those that OEMs may now be purchasing in quantity. Units with similar specifications may engender very different subjective impressions, and thereby give the products that contain them a substantial competitive advantage—or disadvantage.

For battery-powered applications, a display's power consumption (largely a function of the backlight) is a big issue. For monochrome VGA laptop displays, typical luminance-power values are 65 cd/m^2 at 2W.

Recently, some manufacturers of subnotebook computers—such as Hewlett-Packard Co.'s OmniBook 300—have decided to run their LCDs in reflective mode, doing away with the backlight entirely. This design yields a very lightweight computer that operates for hours on a few standard penlight batteries, but it unfortunately compromises image quality in all but bright ambients.

Such problems will not last. All LCD technologies are advancing quickly, with more pixels, finer pixel pitches, more colors or gray levels, and larger screens [see "Xerox's 6.3-million-pixel LCD," p. 21]. The larger screens have diagonals of about 14 inches for commercial "conventional" LCDs and up to 24 inches for Canon's as yet unproved implementation of ferroelectric LCD technology (which has suffered from mechanical instability in previous incarnations).

LARGE-SCREEN LCDs? But they are not considered "really large," and "really large" is an issue. If the high-information–content flat-panel display market is defined at one end by the reality of laptop computers, it is defined at the other by the dream of 60-inch-diagonal, high-definition television (HDTV) screens hanging on the wall.

Currently, only one full-color, video-rate flat-panel technology can be purchased in the worldwide marketplace: color AMLCDs. But, given the problems LCD manufacturers are having with the current 10-inch glass, it is no wonder that they have no immediate plans to process 60-inch glass.

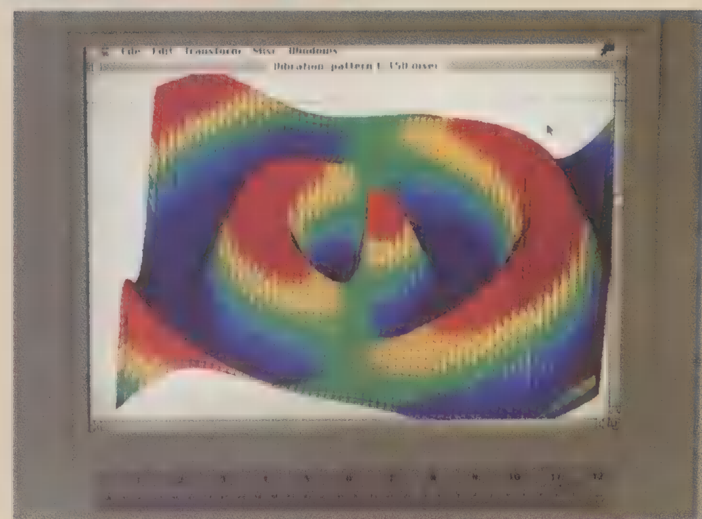
Can LCD technology be a contender in the rich HDTV market that should start developing in 1995? Perhaps eventually. One approach is to assemble small displays into a larger one. The concept is implemented today—crudely—with cathode-ray tubes in "videowalls," but small flat panels would have to be put together seamlessly in a process called tiling. With exquisitely precise control of tile-to-tile alignment, spacing, luminance, and color, researchers think they can make the seams invisible. But making large displays with small-display technology is neither easy nor cheap.

Making a single large LCD could possibly be done with a technology called plasma-addressed liquid crystal, which was first announced three years ago by Tektronix Inc. and shown in a much more refined form at the SID symposium in Seattle [see "Replacing transistors with gas," left].

THE GREAT FLAT HOPE. The most likely candidate for HDTV on a wall in this century is not a variation of LCD technology at all, but a color plasma display panel (PDP). Monochrome (red-orange) PDPs have been built in sizes up to 60 inches diagonal for some time, a size that no other flat-panel technology has ever approached.

Such sizes are possible because PDPs have a fairly simple glass-sandwich structure that scales readily. Monochrome plasma displays use a matrix addressing

Replacing transistors with gas



Tektronix Inc.

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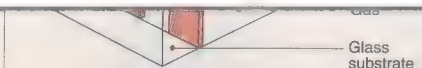
At this year's SID show, Buzak, now director of Tektronix' Display Research Laboratory, was back with a much more polished plasma-addressed liquid-crystal display (PALCD), one having a 16-inch diagonal and 640 by 480 pixels.

The required size and spacing of the plasma channels do not lend themselves to displays with very fine pixel pitches, but the technology is relatively simple, readily scalable, and capable of video speeds. In short, it is a candidate for large-screen, direct-view HDTV.

Tektronix is looking for partners to help convert this well-developed technology into products. Contact Thomas S. Buzak, Display Research Laboratory, Tektronix Inc., Box 500, M/S 46-944, Beaverton, OR 97077.

—*K.I.W.*



scheme to ionize a gas mixture containing neon, and the neon glows with its characteristic red-orange color. In color PDPs, the gas mixture is changed to one containing xenon, which emits in the ultraviolet (UV) rather than the visible portion of the electromagnetic spectrum. The inner walls of the pixels are coated with red, green, and blue phosphors that are UV-sensitive. This is a well-known and highly efficient mechanism for generating light: it is used in millions of fluorescent lamps. (Fluorescent lamps use ionized mercury to

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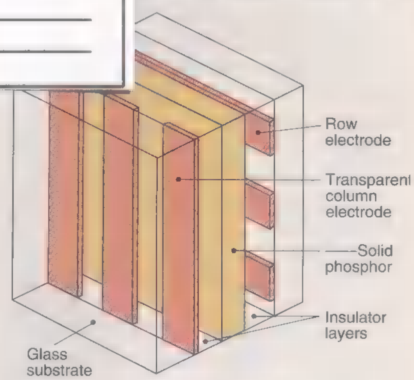

[5] Electroluminescent technology, once a popular display contender, seems to have been relegated to the niche for bright, red-yellow or monochromatic displays, although full-color work is being done with support from the U.S. Advanced Research Projects Agency.

plished with ARPA support, was the development of the most efficient blue phosphor yet. This phosphor is an impressive R&D development, but it allows a white area luminance of only 15 cd/m^2—too dim for a commercial product by at least a factor of four. The consensus in the display community is that unless Planar makes much progress than most believe possible, its work is fated to be a niche technology.

WHAT ABOUT HDTV? Large economical flat-panel displays will not be available for the direct-view HDTV sets to be introduced in 1995. These sets will use conventional cathode-ray tubes having a 16:9 aspect ratio and approximately 1000 raster lines [Fig. 6]. The view of several potential suppliers is that the most common size, at least initially, will have a 32-inch diagonal.

For larger images, consumers will have a choice of projection sets using either projection cathode-ray tubes or an AMLCD of

Sony Corp.

[6] The direct-view high-definition television sets to be introduced in 1995 will not use flat-panel displays at all, but cathode-ray tubes having a 16:9 aspect ratio and over 1000 horizontal raster lines.

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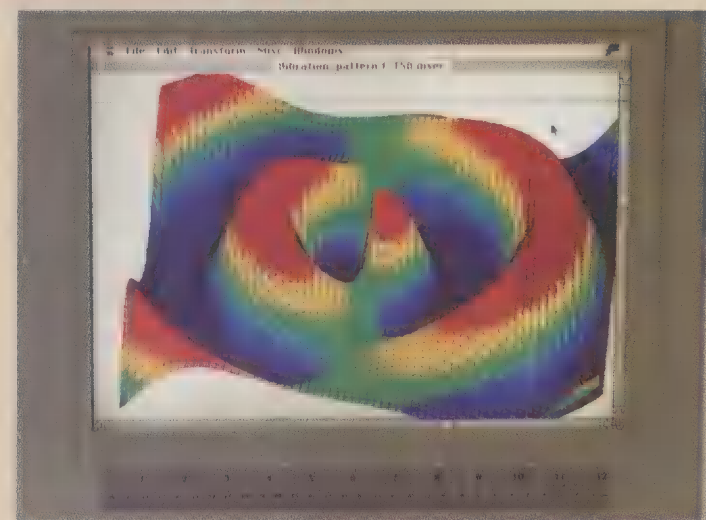

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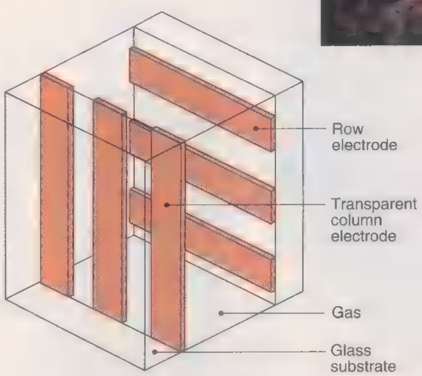
—K.I.W.

[4] Color plasma display technology, which is based on using color phosphors for gas-discharge pixels such as those shown below, is the leading contender for high-definition-television-on-a-wall in this century. Photonics Imaging Inc.'s color panel has a 30-inch diagonal and 1024 by 768 pixels. The photo [right] was taken during the panel's design, and only half of the pixels are lit.

Photonics Imaging



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Japan's NHK Corp. in Tokyo has been developing color PDPs for nearly two decades. Most of this time has been spent on a PDP variant called dc plasma, which is now producing images of high quality but not yet bright enough for commercial products. Recently, the company added a program to develop a variant known as ac plasma.

But at the 1992 SID show in Boston, NHK, Oki, and Texas Instruments (Japan) showed a very impressive dc-plasma HDTV set with a 32-inch-diagonal screen. The image quality and color rendition were excellent and, with a luminance estimated at 75 cd/m^2, the image was almost bright enough for a consumer product. This year at SID, NHK described its work on an improved 40-inch-diagonal dc plasma display.

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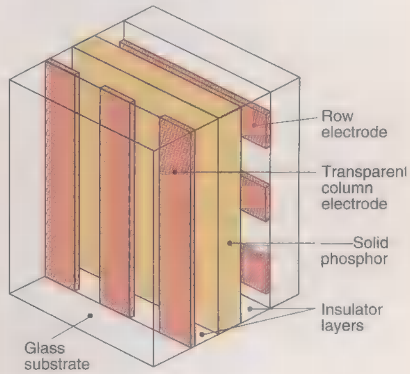
The remaining classical flat-panel technology, electroluminescence [Fig. 5], seems to have peaked. The merger three years ago of Finlux, Espoo, Finland, into Planar Systems Inc., Beaverton, OR, left the world with only two major electroluminescent display suppliers. In addition to Planar, there is Sharp Corp., Osaka, which continues to develop and introduce new products of this type—but in a remarkably understated way.

Planar did create a stir in Seattle by showing the first electroluminescent display that could reasonably be called full-color.

Planar's substantial achievement, accomplished with ARPA support, was the development of the most efficient blue phosphor yet. This phosphor is an impressive R&D development, but it allows a white area luminance of only 15 cd/m^2—too dim for a commercial product by at least a factor of four. The consensus in the display community is that unless Planar makes much progress than most believe possible, its work is fated to be a niche technology.



[5] Electroluminescent technology, once a popular display contender, seems to have been relegated to the niche for bright, red-yellow or monochromatic displays, although full-color work is being done with support from the U.S. Advanced Research Projects Agency.

WHAT ABOUT HDTV? Large economical flat-panel displays will not be available for the direct-view HDTV sets to be introduced in 1995. These sets will use conventional cathode-ray tubes having a 16:9 aspect ratio and approximately 1000 raster lines [Fig. 6]. The view of several potential suppliers is that the most common size, at least initially, will have a 32-inch diagonal.

For larger images, consumers will have a choice of projection sets using either projection cathode-ray tubes or an AMLCD of

Sony Corp.

[6] The direct-view high-definition television sets to be introduced in 1995 will not use flat-panel displays at all, but cathode-ray tubes having a 16:9 aspect ratio and over 1000 horizontal raster lines.

The best of both worlds?

Conventional color cathode-ray tubes are bright and offer high resolution, fast response, a wide viewing angle, and a broad spectrum of colors—at costs that are modest with respect to display performance.

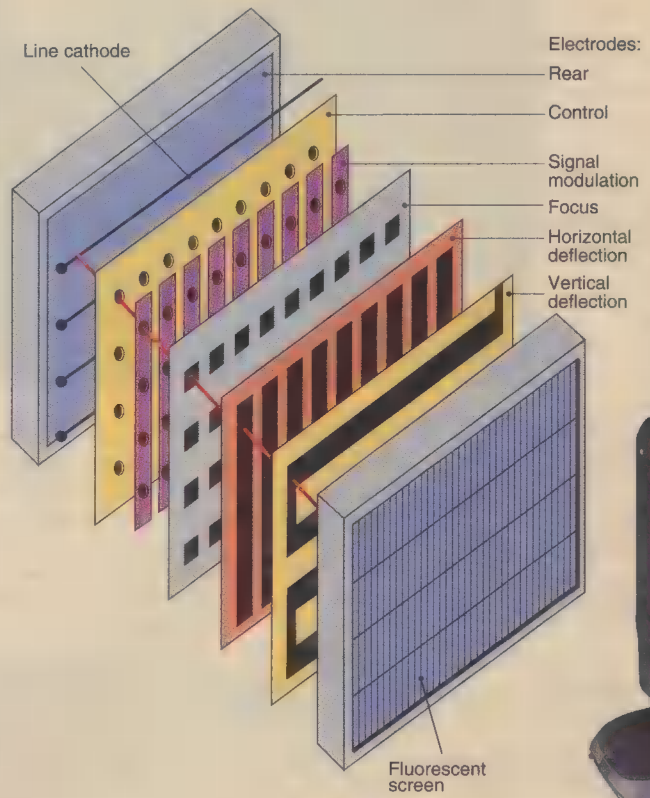
On the other hand, flat panels are, well, flat. It is their flatness, accompanied generally by light weight and sometimes by low power consumption, that is their *raison d'être*.

The designers of most flat panels would be happy to come close to the image quality offered by run-of-the-mill cathode-ray tubes (CRTs). But image quality is not everything. In laptop computers, for instance, users are willing to sacrifice image quality for light weight and long battery life. Starting with W. Ross Alken at the University of California Berkeley, in 1951, periodically designers have tried to come up with flat CRTs that would combine the advantages of both display technologies.

Now, Matsushita Electric Industrial Co., Osaka, has announced the commercial production of a 14-inch-diagonal television receiver based on a cross between CRT and matrix-addressing technologies, which the company calls Flat Vision. Like a conventional CRT, Flat Vision uses a cathode to produce electrons, a deflection system (in this case, electrostatic deflection) to direct the electron beam, and a phosphor screen with red, green, and blue (RGB) stripes, all of which are maintained in a vacuum.

But this is not a single CRT. Contained within one flat, evacuated bulb is an array of many CRTs, built with laminar structures for the sake of relatively economical fabrication. If the system's basic structure were used to make a single, conventional CRT of moderate size, it could not maintain focus and color convergence across the screen. But all of these CRTs are tiny in terms of their pixel dimensions.

The TV set that Matsushita began selling in Japan last month—with 442 pixels horizontally and 440 pixels vertically—has nearly 10 000 CRTs in the array. That comes to 20 pixels per mini-CRT, each of which is turned on at the appropriate time by means of the control electrode [see figure]. Electronically, such a system is very complex, even though switching its matrix of 10 000 elements is much less demanding than switching the nearly one million elements in a full-color LCD.



Matsushita's 14-inch display is 98 mm (3.9 inches) thick. The entire TV set weighs 16.2 kg and consumes 85 W of power. Clearly, substantial weight and power savings are not part of the Flat Vision package. But flatness—in comparison to a conventional CRT—is.

As intriguing as the new technology is, it poses several questions. Is 98 mm thin enough? Can resolution be brought up to the demands of high-definition television and computer monitors? As sizes grow, will the design be susceptible to matrix crosstalk problems? Can the cost be brought down? (The TV's introductory price is ¥288 000, or about US $2700 at the current ¥105 to the dollar.)

Matsushita has clearly answered these questions to its own satisfaction. Sources within the company say that, despite the modest initial production of 1000 units a month, the company's goal is nothing less than head-to-head competition with the world's color LCD manufacturers. It is projecting that Flat Vision will capture 10 percent of the worldwide display market—currently 140 million units annually spread over all technologies—by the year 2000.

Until Flat Vision displays are in wider distribution and subject to independent analysis, it is hard to say whether Matsushita's optimism is justified. But, as the Japanese industrial giant's sole entry in the flat-panel sweepstakes, it certainly gives equipment designers and end users a novel display technology worth considering for future products. —*K.I.W.*

moderate size employed as a light valve. The only other projection technology that could appear in a consumer product within the next three or four years is Texas Instruments' innovative array of deflectable micro-mirrors [see the article, "Mirrors on a chip," by Jack M. Younse, opposite.]

Color plasma is the most likely candidate for a large direct-view flat-panel display in this century, but Tektronix' plasma-addressed LCD is an interesting possibility. And Matsushita entered a dark horse called Flat Vision in the race this summer [see "The best of both worlds?," above].

TO PROBE FURTHER. While there has been a plethora of papers on LCDs, one tutorial that does justice to the electro-optic effects through which LCDs operate (a topic intentionally avoided in the current article) is Terry Scheffer and Jürgen Nehring's surprisingly readable "Supertwisted Nematic (STN) LCDs." It appears in Volume 1 of the Society for Information Display (SID) '93 Seminar Lecture Notes.

The current article's discussion of display addressing borrows from Sheffer and Nehring, but leaves most of their 60 pages untapped. Contact the Society for Information Display, 8055 W. Manchester Ave., Playa del Rey, CA 90293; 310-305-1502.

Two books that survey display technologies in general are *Flat-panel Displays and CRTs*, edited and partially written by Larry E. Tannas Jr. (Van Nostrand Reinhold, New York, 1985), and *Handbook of Display Technology* by Joseph A. Castellano (Academic Press, San Diego, CA, 1992.)

The monthly *Information Display Magazine* contains readable articles and columns on display technology, products, applications, and marketing. It is available with membership in SID or on a controlled-circulation basis. (The society's address is listed above.)

A remarkably rich exposure to display issues, R&D, products, and applications is available at SID's annual symposium and show. The 1994 edition will be held in San Jose, CA, during the week of June 13. Call the society for information. ◆

Mirrors on a chip

A new projection display utilizes reflections from hundreds of thousands of micromirrors, each mounted above its own memory cell

Many large projection displays may quite soon be controlled directly from a unique kind of semiconductor chip—one with a "roof" of seesaw micromirrors, each individually mounted above a memory cell. Displays based on these devices should outperform models based on cathode-ray tubes, and even vie with them in price. Computer monitors and high-definition television clearly stand to benefit. (This month's cover has already benefited.)

This revolutionary new optomechanical technology for digital projection displays is founded on the digital micromirror device (DMD), a spatial light modulator invented in 1987 by Larry J. Hornbeck, a Texas Instruments Inc. scientist. The DMD itself owes the torsion beam support of each mirror to still earlier work at TI on deformable mirror light valves.

In broad outline, the DMD covers each memory cell of a CMOS static RAM with a movable micromirror. Electrostatic forces based on the data in the cell tilt the mirror either +10 degrees (on) or −10 degrees (off), modulating the light incident on its surface. Light reflected from any on-mirrors passes through a projection lens and creates images on a large screen (systems with diagonals of 16 ft have been demonstrated). Light from the remaining off-mirrors is reflected away from the projection lens and trapped. The proportion of time during each video frame that a mirror remains in the on-state determines shades of gray—from black for zero on-time to white for 100 percent on-time. Color may be added in two ways, by a color wheel or by a three-DMD setup in development. The entire system into which the DMD fits is compared in Fig. 1 with projection displays based on either the liquid-crystal display (LCD), or the cathode-ray tube (CRT).

The standard-resolution version of the DMD corresponds to the National Television System Committee (NTSC) or Phase Alternation Line (PAL) standard. It is a chip about 2.3 cm^2 covered by 442 368 movable mirrors, each 16 μm on a side—so small that 4000 of them would be hidden by a human hair stretched diagonally across the device.

Jack M. Younse Texas Instruments Inc.

In operation, the data representing the image is written in highly parallel fashion, two lines at a time, into the static RAM. (In the first prototype designs, the dynamic RAM was not used because of concern that light from the bright illumination source might leak into the RAM and upset the data in the cell.) The static RAM is divided into an upper and a lower half, each edged by 48 input pads. Every input pad has 16 bits of serial data loaded into it, in step with every other 16-bit series—enough to write to the 768 pixels in each row. A picture plane of data can be read into the standard NTSC chip in about 140 μs at rates greater than 30 MHz.

IN CLOSE-UP. The micromirror construction and the underlying electrodes of the DMD chip appear in the insert to Fig. 2. Directly over each memory cell are two address electrodes and two "landing pads" for the seesaw mirror. Above these electrodes is the aluminum-alloy mirror, supported by hinges attached to support posts. The micromirror has three states. It operates in a bistable mode, tilting 10 degrees about the structure's torsion beams in one or the other direction. The third state is a flat position in which the mirrors are parked when the display is turned off. The scanning electron micrograph in Fig. 2 shows mirrors in all three states.

In effect, the mirror plate and the address electrodes form capacitors. When +5 V (digital 1) is applied to one address electrode, 0 V (digital 0) to the other address electrode, and a negative bias to the mirror plate, the electrostatic charge thus created causes the mirror to tilt toward the +5-V electrode. The voltage on the address electrode just starts the mirror tilting, whereupon it continues under its own momentum until it hits the landing pad. Driving the mirrors to the landing pad produces good uniformity across the DMD.

BUILDING THE 'ROOF.' To fabricate a DMD, the standard CMOS processing steps are completed through the static RAM and the offset address electrodes. Then the silicon wafer is completely coated with a polymer layer. The thickness of this layer controls the height of the micromirrors above the silicon surface.

Vias are etched through the polymer layer to the open contact sites, on which are fabricated the support posts for the hinge and mirror assembly. Next a thin aluminum hinge layer and a thicker aluminum mirror layer are deposited, patterned, and etched.

A plasma etch removes the entire polymer layer, leaving the mirrors suspended above the silicon substrate by the hinges attached to the support post. When the structure tilts, the thicker mirrors remain flat and the thinner hinges twist in torsion. The height of this superstructure over the silicon substrate is enough to allow the mirrors to tilt plus and minus 10 degrees about their torsion axis.

In effect, the mirrors have a built-in mechanical memory. Once they tilt in either direction, they stay electromechanically latched in that state by the mirror bias until a reset signal is applied, regardless of the data in the underlying memory cells. This mechanical memory is a handy means of setting all the mirrors simultaneously to the desired state for a given picture plane and then immediately loading new data for the next picture plane into the array. Put another way, the mirrors are unaffected by the data in the static RAM except for the brief time needed to restore them to the flat state and then tilt them to their new positions. Two advantages are gained: the time available for loading the data into the array

Defining terms

HDTV: high-definition TV; the standards are still being defined, but it is widely expected to have a 16:9 aspect ratio, with vertical resolution of 960 lines in the United States, 1152 lines in Europe.

Lenticular screen: a rear-projection display screen with lens-like microstructures and black vertical lines that control the refraction of light at the screen surface to provide enhanced brightness and contrast at expected observer locations.

NTSC: National Television System Committee; the commercial 525-line color TV standard adopted in 1953 for the United States; also used in North and South America and Japan. It has 483 active lines per interlaced TV frame, is specified for 60-Hz operation, and has a 4:3 aspect ratio. The number of horizontal pixels is determined by the sampling rate.

PAL: phase-alternation line; a commercial 625-line color TV standard used in Europe. It specifies 575 active lines per interlaced TV frame, is defined for 50-Hz operation, and has a 4:3 aspect ratio. The number of horizontal pixels is determined by the sampling rate.

VGA: Video Graphics Adapter; a computer display standard with a 4:3 aspect ratio and a 640-by-480-pixel format.

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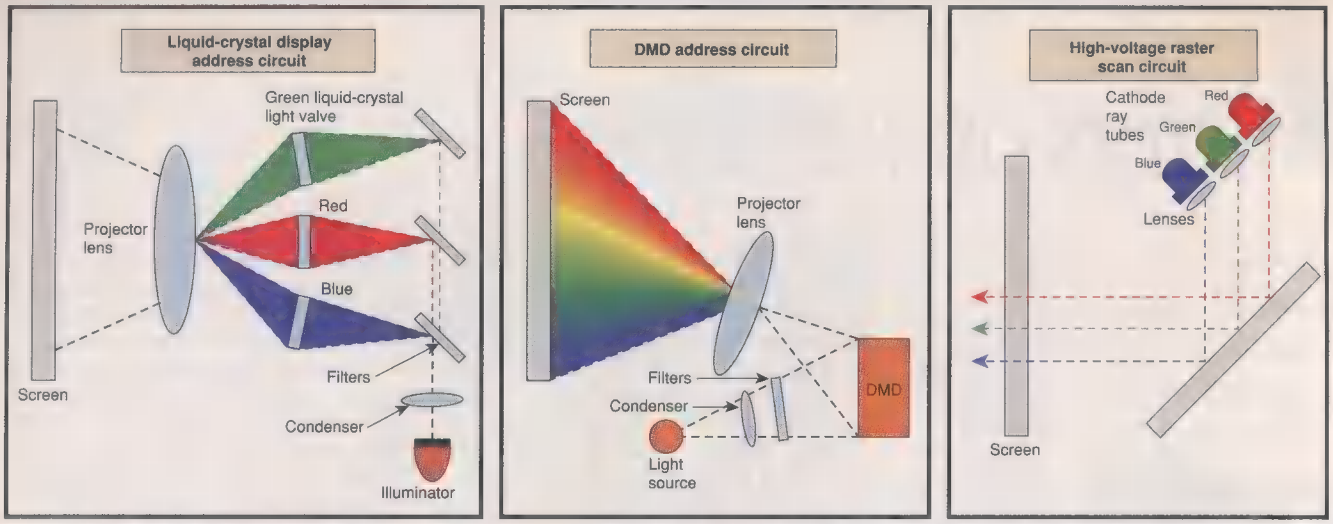
Techniques of projection display



Three-liquid-crystal light valve display | **Single digital micromirror device (DMD) display** | **Three-cathode-ray-tube display**

[1] In current projectors based on liquid-crystal displays (LCDs), dichroic beam splitters supply red, green, and blue light to trios of LCD light valves, which pass or block the light as specified by the pixel data [left]. In the display based on a single digital micromirror device (DMD), ■ synchronized rotating color wheel [not shown] in effect tints the light sent to the DMD chip [center]. Three consecutive 5.6-ms color fields make one 16.7-ms field, for 180 color fields per second. The cathode-ray-tube (CRT) projector contains three CRTs (red, green, and blue), each with its own cooled projection lens [right]. The images converge at a large mirror that reflects them onto a screen. Most CRT displays are rear-projection systems. Current LCD displays are mainly front-projection systems, although rear-projection systems are emerging. The DMD display is suitable for either front or rear projection, with minor modifications to the optics.

is maximized, and the speed demands on the DMD drive electronics are reduced to ■ workable range, below about 30 MHz.

TOWARD HIGHER RESOLUTION. An aggressive proof-of-concept program is currently under way at Texas Instruments, with support from the Advanced Research Projects Agency (ARPA), Arlington, VA, and the U.S. Air Force's Wright Laboratories in Dayton, OH. Its goal is to have ■ prototype high-definition display, based on DMD chips with over 2.3 million micromirrors apiece, up and running by the end of 1993. These chips will serve 2048 by 1152 pixels and be 37 by 22 mm in size, about five times the area of the NTSC chip. The device will have a 16:9 aspect ratio and use the standard 16-by-16-μm micromirror cell.

One of the biggest challenges for such ■ large chip is the lithography required to fabricate it. Only a few steppers available today can use standard 5× photomasks to write over such a large field and still achieve the resolution required. Some 1× steppers might be able to handle the task, but these put a heavy burden on the quality of the reticle. Currently, the high-definition chip is being fabricated with ■ reticle composition technique, where patterns are written in sections and spliced together to provide a virtually seamless large-area DMD chip.

IN ACTION. The digital micromirror device is most effective when coupled with dark-field projection optics [Fig. 3]. Here, a bright light source is directed to the chip at an angle to its surface of approximately 70 degrees—or 20 degrees relative to an axis perpendicular to the chip surface. Mirrors tilted +10 degrees (on) will then reflect the incoming light by a −20-degree angle through a projection lens and onto a screen. Mirrors tilted −10 degrees (off) will reflect the path of the incident light by −60 degrees so as to miss the projection lens aperture and strike a black light absorber. Likewise, flat surfaces such as hinges and support-post tops will bend the incident light by −40 degrees, so that it also misses the projection lens and is trapped.

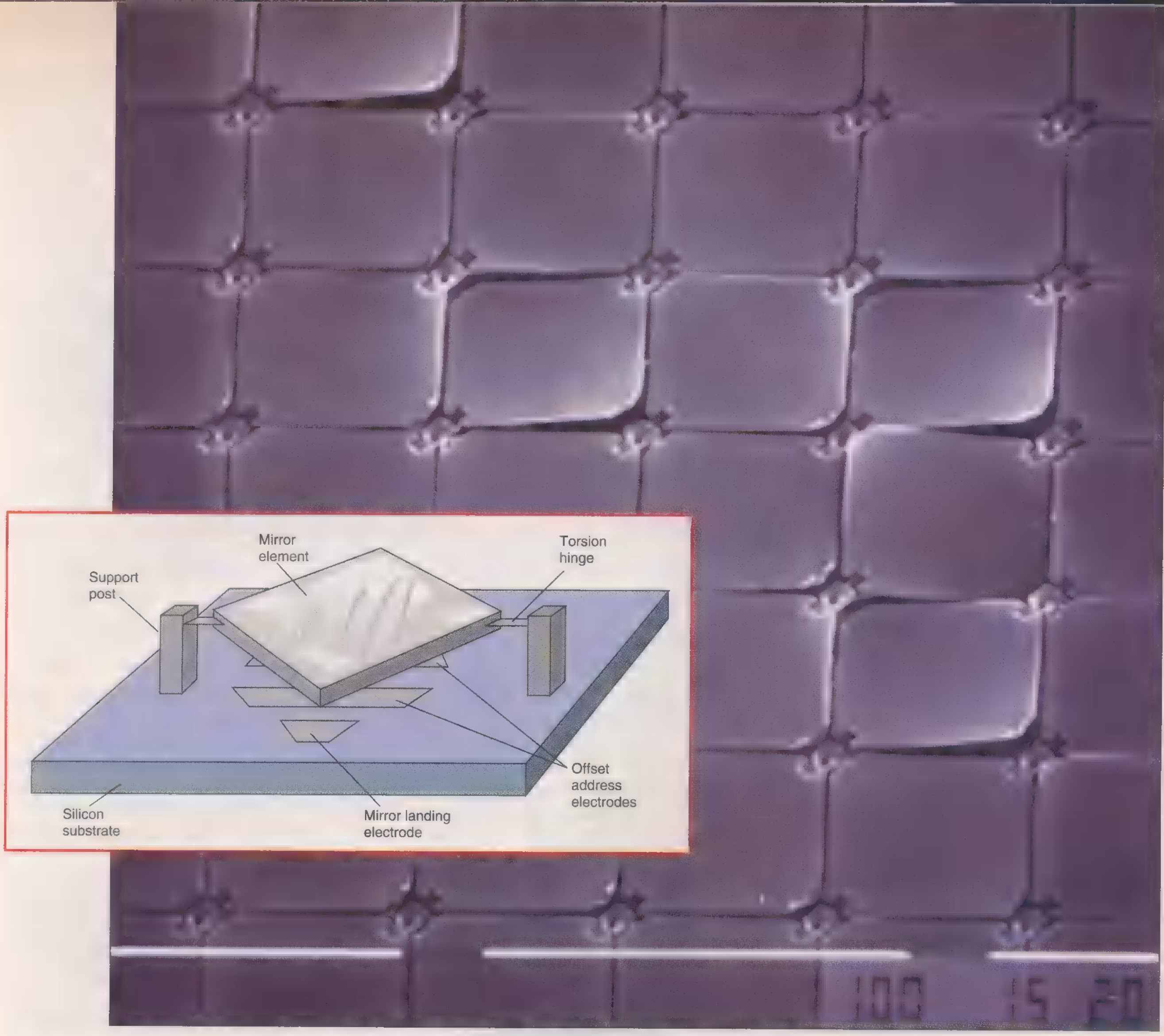
The projection system is depicted in Fig. 4. Additional optical components include two lenses. The condensing lens focuses the incoming light down to the size of the DMD chip so that all the light is used. A zoom projection lens is added to support various screen sizes.

A color projection system based on a single micromirror device also needs a rotating color filter wheel, inserted at the narrowest point along the light path and synchronized to the system electronics. The

Projection systems using digital micromirror devices (DMDs)

Projector characteristics	Single-DMD projector, NTSC-standard display	Projected values for ARPA 3-DMD projector, HDTV display
No. of DMD pixels	768 × 576	2048 × 1152 × (3 DMDs)
No. of active pixels used in demo system	640 × 480	1707 × 960
Pixel size	16 × 16 μm	16 x 16 μm
Pixel spacing (pitch)	17 μm, center to center	17 μm, center to center
Pixel aperture (fill factor)	74%	>75%
Pixel response time	10 μs	10 μs
DMD's optical efficiency	>60%	>60%
Projection type	Front	Front
Screen size	≥52 inches	≥60 inches
Picture aspect ratio	4:3	16:9
Color frame rate	180 Hz	60 Hz
Screen brightness	220 lumens	>2000 lumens
Light source	1000 W, xenon arc	575 W, metal halide
Contrast ratio	>50:1	>100:1
Gray-scale capability, per color	8 bits (256 shades)	8 or 9 bits
Color generation method	Rotating color wheel	Color prism
Pixel convergence	Self-aligned	Optical

NTSC = National Television System Committee; ARPA = Advanced Research Projects Agency.



[2] A scanning electron micrograph of a portion of the digital micromirror device (DMD) shows micromirrors in all three positions: flat, on, and off [see column of mirrors on the left of the image]. Each mirror element is 16 μm on a side. In the aluminum-alloy micromirror superstructure [inset], the mirror is suspended above the surface of the chip by support posts and the torsion hinges. It tilts into the on- or off-state when 5 V is applied to one of the two offset address electrodes (the other is grounded). The tilting motion is held at plus or minus 10 degrees by electrostatic forces. Invisible beneath the electrodes is the static RAM cell.

filter lets light of the primary colors—red, blue, and green—fall in succession on the surface of the DMD, each for a total duration of a third of the TV field (approximately 5.6 ms).

Shades of gray or color are accomplished by clocking the mirrors with a type of pulse-width modulation, so that they remain in the on-state during each TV frame for a time that is proportional to the level of gray or color desired. The conventional 8-bit system supplies 256 quantized levels for each color; that makes it possible to display more than 16 million (256^3) colors from the three 8-bit primary colors. For example, if the pixel were set at level 128, the mirror would remain in the on-state for one half the time. The human eye, being part of the overall optical system, integrates the light during each frame so that the correct hues or shades of gray are seen.

A high-definition display system based on three micromirror devices is currently under development at TI. The project has strong support from ARPA, which has long acted on its interest in high-definition display systems by investing in promising display technologies throughout the United States. A TI subcontractor in this program is the David Sarnoff Research Center in Princeton, NJ; its responsibility is the optical subassembly and the front-end electronics needed for the high-definition video source to the prototype projector.

This system will use three 2048-by-1152-pixel DMDs and will be one of the world's first truly digital high-definition displays. If successful, the program will have demonstrated long technical life for DMD displays as a system that supports both the current requirements in HDTV and those that will evolve over the next two decades. Measured performance characteristics for the single-DMD projector and expected performance characteristics for the three-DMD system are shown in the table.

The DMD is a progressive scan device, addressing every line of the display during each TV field, which means every 1/60 of a second for NTSC displays. This is both an advantage for the future and a minor drawback for the present.

Conventional CRTs operate in the interlace mode, in which every other line is written during one 1/60-second field and the alternate lines are written during the subsequent field. The glow of the phosphor in the CRT persists long enough for this technique to work. But the DMD, having no persistence, must write the entire picture every 1/60 of a second and receive data at twice the rate of the CRT. The faster electronics this necessitates makes the DMD well suited for future progressive displays. But some adjustment must be made if it is to display the video available today.

A number of methods can be employed. Two simple techniques are line doubling, which displays each line twice, and field

jamming, in which the current field is superimposed over the previous field. But, depending on the content of the scene, these approaches can cause picture artifacts. A smarter idea is to use motion-adaptive algorithms implemented in hardware and software. This technique converts interlaced video into progressive scan and has been shown to be quite effective. Such an approach is currently being developed for the DMD.

STAR PERFORMANCE. Resolution, brightness, contrast, gray scale, color fidelity, and pixel response time (speed)—on all counts the DMD scores, if as yet mainly in the prototype. High resolution is inherent since the basic pixel cells are spaced on 17-μm centers both horizontally and vertically. Existing photolithographic techniques suffice, since they allow chips with hundreds of thousands or even millions of pixels to be fabricated.

The brightness of the device is due to the high reflectivity of the micromirrors (more than 90 percent for visible light) and the fact that they cover at least 75 percent of the chip surface. The remaining space consists of approximately 1-μm gaps between the mirrors, posts, and hinges. Overall, taking into account mirror reflectivity, active surface area, and such other diffractive effects as the light scattered from the mirror edges, hinges, and support-post corners, the device's optical efficiency is better than 60 percent.

When the micromirror and liquid-crystal type of projectors are compared for brightness, it pretty much boils down to the optical efficiency of the two spatial light modulators, since both projectors would be expected to use comparable light sources and optics. LCD technology is making large strides in this area, but at present, DMDs are two to three times more efficient. It is estimated that the three-DMD high-definition display currently under development could attain over 2000 screen lumens, assuming a unity-gain, front-projection screen with a 60-inch diagonal.

Contrast ratio also matters a lot in a projection display. A single-DMD projector demonstrated earlier this year has exhibited a contrast ratio exceeding 50:1, and recent results in the laboratory have shown contrast ratios more than twice as good. The DMD, being a fully digital device, measures its gray-scale capability in bits; typically 8 to 10 bits are obtainable. This translates into 256 to 1024 levels of gray for a monochrome display or for each primary (red, blue, and green) color for the more popular color projector. For example, an 8-bit color projector can generate 16 777 216 colors from 256 shades of the three primary colors. As a result, excellent color fidelity is realized by a DMD projector.

An advantage of the single-DMD projector is that the pixels are self-aligning, since each pixel reflects all the primary colors in turn. However, if the observer moves his or her head quickly relative to the screen, the color may appear to break up because of the use of a color wheel. This artifact seems not to be a serious problem for normal viewing of the display and with proper clocking of the DMD can be removed.

Although single-DMD projection systems suit low-cost consumer applications, the three-DMD variety should perform much better. For one thing, these systems are much brighter. Some two-thirds of the available light is lost in a single-device, sequential-field color system because the light is filtered to give red light for a third of the TV field, green light for another third, and blue light for the last third. In the three-device system, constant red, green, and blue light is available at each DMD for most of the TV field.

RELIABILITY. The ability of the DMD to withstand the wear and tear of long-term everyday use is essential to its success. The chips will be mounted in hermetic packages, and indications are that they should meet the temperature and environmental requirements for commercial or rugged military applications. A lot of testing must still be done in this area, but the results so far are encouraging.

One of the biggest worries many have had is the durability of the mechanical hinges. So far, many DMD chips have been tested, with every hinge exercised for several hundred billion cycles, the equivalent of about four years of continuous operation for a TV. None has shown problems with hinges breaking due to fatigue.

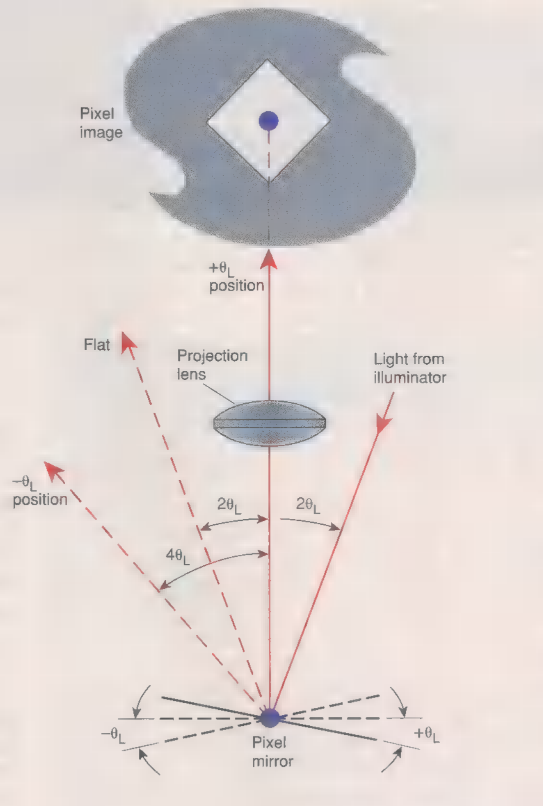
THE BOTTOM LINE. DMD technology promises to have a number of cost advantages. First, the micromirrors are fast: they can switch from being fully on to being fully off in about 10 μs. So a projection display can be based on a single DMD in field-sequential color operation. As a result, a TV field of data can be read in and displayed in one-third the time of a CRT projection display, as well as most LCD projection displays available today. So the single-DMD projector, with its simple optical components and the self-aligned convergence of the pixels, will make an attractive and relatively inexpensive display possible.

Secondly, the fabrication of the micromirror devices relies on standard semiconductor tools and mostly standard processes: even the new processes required to form the mirror layers can be carried out on existing equipment. As a result, the decline in production cost with the rise in volume can be predicted with a fair degree of confidence.

In fact, the CMOS memory underlying the micromirror structure can be manufactured on the same production lines as conventional memory chips. And although the micromirror structure is unique, the DMD was deliberately designed to use only well-known semiconductor processes. Here the advantage is that the DMDs can be manufactured side by side with other semiconductor chips, helping to fill existing factory capacities and thereby reducing capital expenditures. They are also highly compatible with other highly specialized application-specific ICs, which can be used to provide fully digital solutions for the high-volume consumer market.

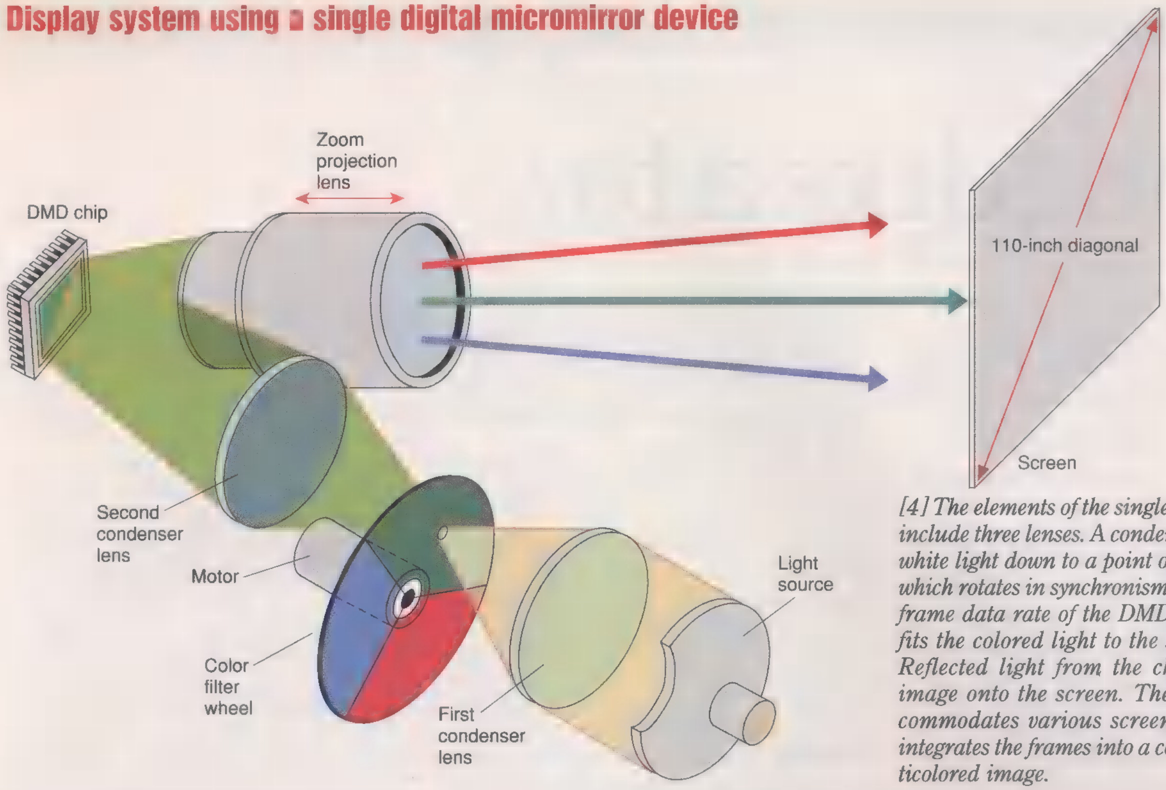
COMING SOON. Today, large-screen direct-view displays are mostly of the CRT type. But for screen sizes beyond about 38 inches on the diagonal, the glass envelopes become very heavy, bulky, and hard to handle. Therefore, for very large displays, digital projection technology looks and will probably continue to look attractive through the remainder of this century.

Whether they have the 4:3 aspect ratio of NTSC or the 16:9 aspect ratio of wide NTSC or HDTV, projection displays are primarily of two types. The 6- to 9-inch projection CRTs familiar from consumer products dominate, but then there



[3] Micromirror elements at an angle of $+\theta_L$ to the chip surface (the on-mirrors) reflect the light from the illuminator through the projection lens and onto the screen. The off-mirrors (at $-\theta_L$) and flat surfaces like the support posts reflect light away from the projection lens and toward a black light-absorbing material.

Display system using a single digital micromirror device



[4] The elements of the single-DMD projector include three lenses. A condenser lens focuses white light down to a point on a color wheel, which rotates in synchronism with the picture frame data rate of the DMD. A second lens fits the colored light to the size of the chip. Reflected light from the chip projects an image onto the screen. The zoom lens accommodates various screen sizes. The eye integrates the frames into a continuous, multicolored image.

are the spatial light modulators: DMDs are in the wings and LCDs are actually beginning to appear commercially [Fig. 1, again]. (For more on display technology see "The flat panel's future," by Kenneth I. Werner, p. 18, this issue.)

Projection CRTs, however, appear limited by the insufficient brightness of their phosphors, a deficiency that LCDs and DMDs can remedy. Moreover, DMD technology has to date been used in standard NTSC projectors and in others with Video Graphics Adapter (VGA) resolution. It is currently being ported to HDTV resolutions. By the year 2000, HDTV will in all likelihood be playing a significant role in combined entertainment, computing, and communications systems intended for home and business environments. Displays will feature wall-size projection screens having 1000 lines or more—over twice the resolution of today's TVs.

But before projection HDTV can be completely realized, some nontrivial engineering obstacles must be addressed. Future spatial light modulators will need to have higher resolution—up to 2 million pixels—and wider 16:9 aspect ratios. Chip sets capable of supporting input data rates greater than 30 MHz will require higher bandwidths. Contrast ratios of better than 100:1 are also desirable in these large-screen projectors.

New and higher-resolution screens will also be needed, especially for rear-projection applications. Front-projection screens exist today for displaying these high-definition pictures. However, high-resolution varieties of the lenticular-type screens used in rear-projectors must still be developed.

In conclusion, because CRTs are already being built in large volumes, they are well down the cost learning curve. So if spatial light modulators can enter the market at cost parity, as seems possible, there should be an advantage as volume drives their cost down. Of course, CRT projection technology will keep on improving and keep the pressure on as a viable competitor to light modulators in the marketplace.

TO PROBE FURTHER. An overview paper on the deformable mirror (now called the digital micromirror) spatial light modulator by Larry Hornbeck can be found in *Proceedings of SPIE*, Vol. 1150, Aug. 6, 1989. Two recent papers are "The digital micromirror device and its application to projection displays," by Jeff Sampsell in Society for Information Display (SID), May 18, 1993, and "The digital micromirror device and its transition to HDTV," by Jack Younse and Dave Monk in *EuroDisplay 1993,* Le Club Visu and SID, Strasbourg, France, Sept. 1, 1993. James Florence discusses DMD technology in "Optical characteristics of the deformable mirror spatial light modulator," in *Technical Digest on Spatial Light Modulators and Applications,* Optical Society of America, 1990, Vol. 14, pp. 166–169.

Three papers on the use of DMD technology in applications other than displays are: "Micromechanical spatial light modulator for electrophotography printers," by Ed Nelson and Larry Hornbeck, in *Proceedings of SPSE, Fourth International Congress on Advances in Non-Impact Printing Technologies*, 1988, p. 427; "Coherent optical correlation using a deformable mirror device spatial light modulator in the Fourier plane," by James Florence and Richard Gale, *Applied Optics*, Vol. 27, 1988, p. 2091; and "4 × 4 fiberoptic crossbar switch using the deformable mirror device," by Gus McDonald, Mark Boysel, and Jeff Sampsell, in the *Technical Digest on Spatial Light Modulators and Applications,* Optical Society of America, 1990, Vol. 14, pp. 80–83.

Pioneering work on spatial light modulators for projection displays is described in the following articles: "An array optical spatial phase modulator," by K. Preston Jr., in *Proceedings of the IEEE International Solid State Circuits Conference*, 1968, p. 100; "A new Schlieren light valve for television projection," by J.A. van Raalte, *Applied Optics*, Vol. 9, 1970, pp. 2225–30; and "The mirror-matrix tube: a novel light valve for projection displays," *IEEE Transactions on Electron Devices*, Vol. 22 , 1975, pp. 765–775.

DMD inventor Larry Hornbeck will discuss recent advances in the technology in an invited paper at this year's International Electron Devices Meeting (IEDM) in Washington, DC, in December. ✚

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Keeping chaos at bay

Electronic circuits are in many ways ideally suited to the latest work in the study of chaos: the application of techniques for controlling it

The scientifically inclined reading public probably has as acute an awareness of chaos as of any other sometimes bewildering phenomenon on the frontier of science. In often eloquent words and striking pictures, science writers and photographers have shown how chaos literally surrounds us in daily life, in the weather around us and in the dripping of an old faucet.

Scientists themselves are finding that chaos can be quite useful in a wide variety of fields. But as anyone who has been kept from sleep by plashing in a sink or caught in an unforecast thunderstorm might testify, the control of chaos may be even more useful.

This very area of endeavor, not even four years old, is one of the latest and most promising in the study and application of the principles of chaos. Already it has yielded strategies for controlling heart arrhythmias and for boosting the power of a laser with potential applications in optical storage. Some chaotic chemical reactions have also been controlled and converted into periodic behavior, which may one day improve efficiency in industrial plants.

The work springs from the recent discovery that the fundamental properties of chaotic systems make them easy to manipulate. For example, in a chaotic electronic circuit, the chaotic voltage or current will never repeat itself. But with tiny nudges to the system, the signal can become periodic, with a choice of many period lengths. Another possibility is to quench the chaotic oscillations altogether so that the system remains free of any and all oscillations.

As it turns out, electronic circuits are an ideal tool for studying chaotic dynamics and control. They have yielded some of the most intriguing results reported so far. Encrypted information, for example, has been communicated using a pair of identical nonlinear circuits synchronized by a chaotic signal. In another circuit, binary coded messages were transmitted by controlling chaotic oscillations that bounced unpredictably between two states. The ability to choose one of a number of different behaviors and switch between them makes it possible to optimize efficiency.

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All chaotic systems have several properties in common, so that simple circuits are analogous to much more complicated ones, like lasers. Consequently, the methods developed to control chaos in electronic circuits are applicable to many diverse physical systems. The controlling device itself is a high-speed analog circuit. In applying perturbations, no calculations are made; instead, trial-and-error adjustments are used to locate the desired behavior.

A PRIMER. Any appreciation of the significance of controlling chaos must be based on an understanding of what chaos is—and is *not*. Chaos is often mistaken for random noise. While chaotic behavior does appear random, it is actually predictable for short periods of time, because the motions follow known physical laws. One of the many surprising aspects of chaos is that it often appears in seemingly simple systems or equations [Fig. 1]. In fact, many of the electronic circuits described later are easily breadboarded with a few inexpensive components; the reader is encouraged to experiment.

The hallmark of chaos is the extreme sensitivity of chaotic systems to their initial conditions. This hypersensitivity is called the butterfly effect, an allusion to the suggestion that a butterfly fluttering its wings somewhere in, say, Brazil on a Monday can roil the weather in New York City on Friday. In other words, a small nudge to an object on some chaotic trajectory can dramatically transform its future. In mathematical terms, any uncertainty, or tolerance, in an output variable grows exponentially, on the average, when repeatedly iterated to successive values of that variable. Figure 1 illustrates this property.

Now consider an electronic circuit. Flowing through this circuit is an oscillatory current having a series of peak amplitudes, whose magnitudes seem random. Suppose we measure one peak as accurately as possible, and then record the next several peaks and label this series "path 1." We go on measuring the peaks until we find one that, to the best capability of our instruments to detect it, has the same height as the first peak in path 1.

We now record the next several peaks and call this "path 2." Since electronic circuits obey simple rules and equations, we would expect paths 1 and 2 to be identical. In a chaotic system, however, not only do the two diverge, but on average they diverge exponentially. Although our best measurements indicated that the paths started at the same point, there is always some tiny, impossible-to-measure difference that shifts the paths along very different trajectories. Thus even if we know the equations that govern the flow of electrons in the circuit, we cannot predict the flow for any significant length of time. This is because the uncertainty in the initial measurement will be amplified and become overwhelming after just a few oscillations.

Furthermore, the return map—a plot of the next amperage peak vs. the present amperage peak—reveals information about our chaotic system. Remarkably, random-looking data, when plotted in this way, may form a figure with a definite structure. This map is one way to view what is referred to as the system's attractor—the confined region of the system's motions.

INTO THE MAELSTROM. Two ways in which the behavior of a system can become chaotic are period-doubling and quasi-periodicity. Period-doubling is the most common. Systems that take this route to chaos will settle into a state of regular, periodic output once the driving force falls within some range of values. In the case of a leaky faucet, for example, when the flow rate is at a certain value, drops may fall every second. This stable condition is known as the period-1 state.

As the driving force (the faucet's flow rate) is increased, the period-1 state eventually becomes unstable. From the faucet, with its maddening drip, drip, drip, there might be a sudden rhythm change to drip-drip, drip-drip, drip-drip. This new rhythm will have a period of a little less than twice the previous one. This is the period-2 state, and the transition to it is called a period-doubling bifurcation. In a circuit, the system suddenly starts oscillating in such a way that successive current peaks alternate between two different heights, suddenly doubling the time the system takes to repeat its motion. In these cases the return map would appear as two points.

This process continues as the bifurcations occur with successively smaller changes in the variable parameter. In the return map, the two points can be seen becoming four, then eight, sixteen, and so on, indicating that the stable states of the system are doubling as the driving force is

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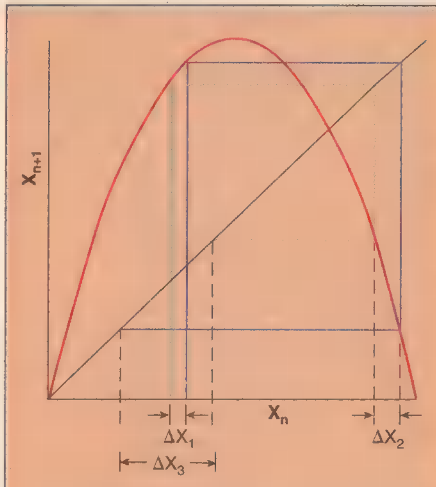


[1] Sometimes chaos is more formally called deterministic chaos to emphasize that these systems, while ultimately unpredictable, still obey the laws of physics or straightforward equations. The following standard example can be demonstrated on a pocket calculator. Consider $X_{n+1} = \lambda X_n(1-X_n)$, known as the logistic equation. A plot of X_{n+1} vs. X_n gives a simple parabolic map. Pick a number between 0 and 1 for X_n, calculate X_{n+1}, plug the result into X_n, and repeat. Graphically this is done by drawing a line from a point on the horizontal axis to the curve, then a horizontal line to the diagonal, followed by a vertical line back to the curve, and so on. For $1 < \lambda < 3$, any starting value of X_n, after a number of iterations of the equation, will settle onto a single value. This value will lie on the intersection of curve and diagonal. This is called the period-1 fixed point. If λ is now increased, at $\lambda = 3$ the slope at the fixed point becomes less than −1, causing the fixed point to become unstable, and the equation ricochets between two new values. This period-doubling, as it is called, continues if λ is increased further, so that the numbers repeat every fourth calculation, then eighth, and so on, until the numbers you see on your calculator never repeat at all and appear to be quite random. In the figure, two nearby values of X_n follow increasingly different paths after only a few iterations as the distance between them widens. The values of X_n are chaotic at this point, yet it is a deterministic system, because every X_{n+1} is uniquely determined by λ and X_n.

increased. After enough time has elapsed, the period doublings become extremely close together, and the orbit no longer regularly visits these islands of stability. Finally it becomes chaotic.

Another common route to chaos, a little more complicated than period-doubling, is the quasi-periodic one. As the drive force, or drive parameter, is increased, the initial, periodic, signal is suddenly modulated by a new, independent, frequency. This spontaneous appearance of a second frequency brings on a new, quasi-periodic, state.

The state is characterized by its winding number, defined as the ratio of the second frequency to the first. In this mode there is no hypersensitivity to initial conditions, so that two neighboring trajectories will remain neighbors indefinitely. The orbits in this state will never close on themselves, hence the term quasi-periodic. As the drive parameter is further increased, the quasi-periodic behavior eventually becomes phase-locked, then turns chaotic. Often, a third frequency, or period-doubling, appears near the transition to chaos.

ELECTRONIC CHAOS. The first glimpse of chaos in electronics was observed by Robert Shaw and some of his colleages in the late 1970s at the University of California, Santa Cruz. They were using an analog computer to solve a nonlinear differential equation representing a mass on a nonlinear spring, with damping, driven by a sinusoidal force. This spring was such that the restoring force had a linear term and a cubic term. The equation of motion was set up on the analog computer and solved with a feedback loop, so that the solutions could be observed directly on an oscilloscope screen.

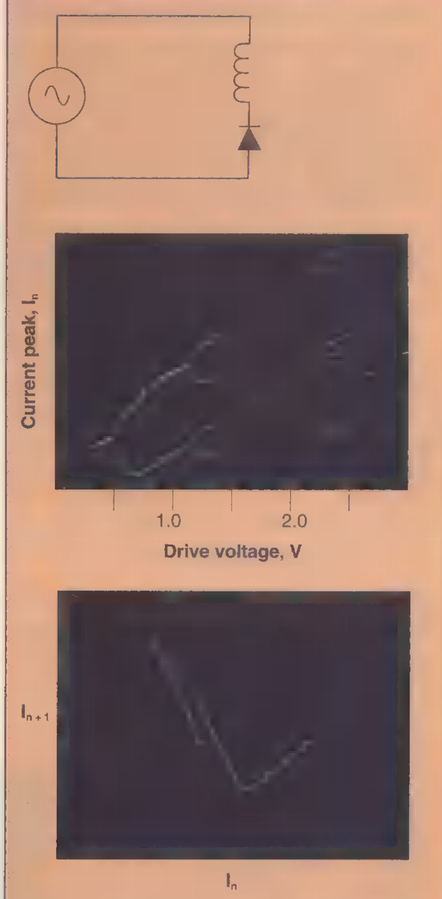
The group saw that with little or no driving force, the particle (mass) follows a period-1 orbit. As the force grows stronger, the nonlinear term in the restoring force becomes large enough to destabilize the period-1 orbit, which doubles. The period-doubling route is followed until chaos is reached.

Electronic chaos is not limited to equations solved on analog computers; some circuits behave chaotically because of the physical properties of semiconductors. One of the first and most studied of these is the diode resonator, which was discovered by Paul Linsay of the Massachusettes Institute of Technology in Cambridge [Fig. 2, top]. This simple circuit consists of a series combination of a 10-to-100-mH inductor and a p-n junction rectifier-type diode. It is driven by a signal generator in the range of 50–100 kHz. As the amplitude of the drive is increased, the current through the system period-doubles to chaos.

The circuit is easily constructed and almost always works. The period-doubling and chaos can be observed by using an oscilloscope probe to measure the voltage across the diode. Furthermore, there is an indicator that the system is not just noisy. The main feature of chaos is that it is predictable for a while. If one triggers the oscilloscope on the largest peak, for example, and observes subsequent peaks, the first few are well defined but then become fuzzier. The sharper the triggering on the largest peak, the longer the well-defined peaks last. This, by the way, is an excellent way to observe the sensitivity to initial conditions found in chaotic systems.

The chaotic nature of the diode resonator's behavior is clear from its bifurcation diagram and map [Fig. 2, middle and bottom]. The bifurcation diagram is a plot of a chaotic variable (the peak forward current through the diode) as a function of the drive parameter (in this case, the generator voltage). It shows where the oscillating system period-doubles and reaches chaos. By following the plot for increasing values of the drive voltage, marked on the abscissa, the values of the peak current can be seen doubling, quadrupling, and so on as the system's behavior advances toward chaos. One can see up to period-8 before chaos appears.

What causes such complex behavior in such a simple system? It is the same phenomenon that limits the speed of a computer, namely, the delayed recovery of the diode coming out of saturation. The delay is caused by the unrecombined charges that have crossed the junction. If the current is reversed, those charges can return, making the diode act like a battery. As the current passing in the forward direction increases, so does the amount of charge returning. The connection with the previously described iterations on the map



[2] The diode resonator is one of the circuits that can behave chaotically. The bifurcation diagram shows the state of the system moving from period-1 to -2 to -4, and so on into chaos, as the drive voltage is increased. The return map, or attractor, shows the amplitude of the next amperage peak, given the amplitude of the present one; the dot is the controlled period-1 state.

is evident: the current in one cycle depends on the current during the previous cycle. For this system, that dependence is described by the shape of the object in the lowest image in Fig. 2.

Coupling two diode resonators together [left in Fig. 3] produces a circuit that follows the quasi-periodic route to chaos. As the drive voltage is increased, the circuit period-doubles and then spontaneously becomes modulated by a new frequency. The currents flowing in the two branches (while in the quasi-periodic state) appear on the x and y axes of an oscilloscope [right, in Fig. 3]. At first, the two frequencies are incommensurate, but as the drive is increased, they eventually phase-lock. Further increasing the drive results in a rich variety of phenomena, including more period-doubling, another oscillation at a third frequency, and, ultimately, chaos.

Chaos can also be found in systems that oscillate without an external generator. The first and most famous circuit of this type was invented in 1983 by Leon O. Chua of the University of California at Berkeley. Chua's circuit, as it is known, is very simple and easily breadboarded [Fig. 4, top].

Underlying its operation is the principle of negative resistance, widely used in microwave and millimeter-wave oscillators. Certain diodes, notably tunnel and Gunn diodes, have a short negative-resistance region in which increasing voltage yields decreasing current, a property that can be exploited for amplification or oscillation. Chua's circuit, though, uses a nonlinear, negative resistance, which is typically produced by linking together ordinary active devices, resistors, and diodes [Fig. 4, top].

In this circuit, the oscillations arise from the unstable power balance between the positive and negative resistances and are sustained by the energy-storing inductor and capacitors. The kinks in the resistance curve [Fig. 4, bottom left] provide the nonlinearity that causes the oscillations to be chaotic. These oscillations can be viewed by placing scope probes on either side of the positive resistor and applying these two voltages to the x and y axes of an oscilloscope.

The circuit displays a wealth of behaviors. If the positive resistance is much larger than the negative, the voltages are dc. As the positive resistance is decreased somewhat, a periodic oscillation spontaneously appears. Further lowering of the resistance brings on period-doubling and chaos. The oscillations as viewed on the scope are confined to one well until the resistance is decreased to the point where two wells are visited. This double-well object is known as the double-scroll strange attractor [Fig. 4, bottom right, in red].

STABLE ORBITS. The earliest work on controlling chaos was done by Edward Ott, Celso Grebogi, and James Yorke of the University of Maryland in College Park. They developed an algorithm, sometimes referred to as the OGY method, for calculating the perturbations needed to stabilize a periodic orbit in a chaotic system.

The method has been likened to balancing a marble on a saddle. If the marble is placed anywhere on the saddle except the exact center, it will fall off. If it is close to the center, nudging the saddle itself in the proper direction will move the marble onto the part that naturally sends the marble back towards the saddle's center.

In a chaotic system, all periodic orbits exist simultaneously and unstably, and in such a way that the motion of the system constantly evolves from one orbit to another. What Ott and his colleagues proposed was to wait until the chaotic system approached the desired orbit, then change one of the system parameters for one period of the chosen orbit. If the maneuver is properly executed, when the parameter is switched back to its initial setting, the system settles onto the desired orbit. When the system inevitably starts to stray from this orbit, the process is repeated. It should be emphasized that the sensitive nature of chaos—the butterfly effect—mandates the use of only the smallest parameter changes.

The method was demonstrated by its inventors in a computer model, and a number of physical experiments soon followed. The first was done by William Ditto, Mark Spano, and Steven Rauseo of the Naval Surface Warfare Center, Silver Spring, MD, and involved stabilizing a gravitationally buckled magnetoelastic ribbon. A long thin piece of this ribbon is stood on its end like an inverted pendulum, and placed in both steady and oscillating magnetic fields. The ribbon cannot completely support its own weight, so it sways back and forth chaotically. The Navy researchers found that by tweaking the dc field according to the OGY method, they could stabilize period-1 and period-2 oscillations.

The slowness with which the ribbon flopped back and forth (only about once per second) made the experiment easy to control by computer. On such a time scale, there is ample time to calculate and implement the perturbation required.

Similar slow systems have been controlled with computer aid, using variations of the OGY method to calculate the necessary nudges. Kenneth Showalter of West Virginia University, Morgantown, and Roger W. Rollins of Ohio University, Athens, each led groups that controlled chaotic chemical reactions. Ditto and Spano teamed up with Alan Garfinkel and James N. Weiss of the School of Medicine, University of California at Los Angeles, to control fibrillations in rabbit heart muscles.

In all these experiments, a computer was used to sample the chaotic variable and calculate the correction signal. Systems that oscillate much faster, however, leave the computer far behind and must be controlled by another method.

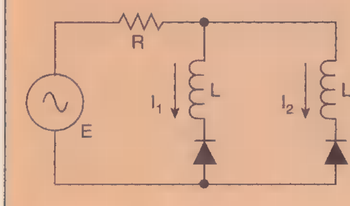
OPF VS. OGY. The method is called occasional proportional feedback, or OPF. It is a modification of the OGY method.

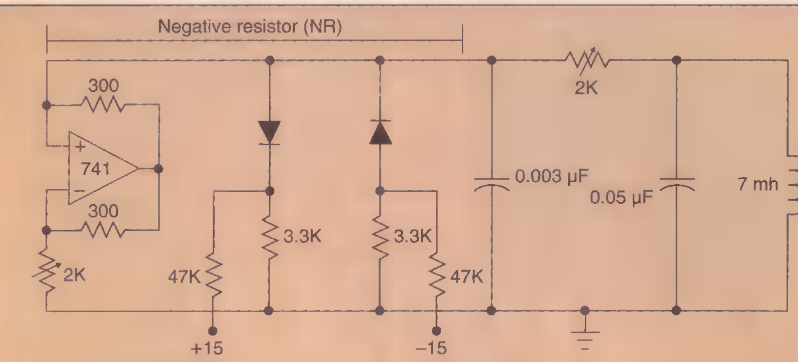
Suppose the OPF method were used to control chaotic oscillations of current through the diode resonator to a period-1 orbit. The technique is best understood from the resonator's return map [Fig. 5]. As the drive voltage applied to the resonator increases, the whole map moves proportionally up the diagonal, and this can be used to advantage. When we measure one peak, I_n, we can move the map up or down so that we have some control over where I_{n+1} falls. So we wait until the current I_n falls near the period-1 fixed point (where the attractor intersects the diagonal and, therefore, $I_{n+1} = I_n$), then measure I_n and immediately alter the drive in such a way that the new map has I_{n+1} at the height of the fixed point. The result is that I_{n+1} falls on the fixed point, or at least closer to it.

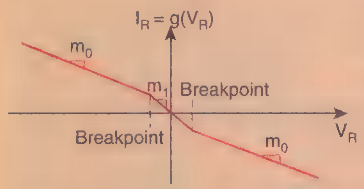
In Fig. 5, the blue map is the original regime of operation. It is measured [labelled 1], and the drive is altered so that the system moves to the red map [2] for just one cycle. This way, I_{n+1} falls right on the fixed point of the original blue map [3]. Once on the fixed point, it takes a few iterations before it falls away from this unstable orbit. However, leaving the control system on ensures that the current will never stray from the stable period-1 orbit.

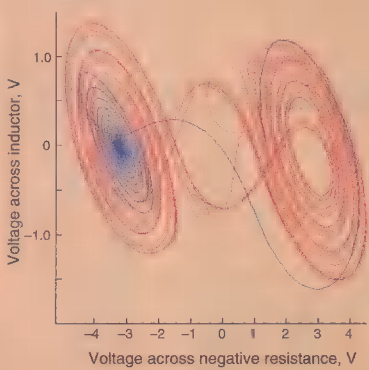
In the OPF method, the perturbation that is applied to the driving voltage is propor-

[3] A second branch in the diode resonator causes it to take the quasi-periodic route to chaos. The currents in the two branches, applied to the axes of an oscilloscope, produce the folded torus known to the authors as the "Klein bottle condom."









[4] Oscillations in Chua's circuit [top] are due to an unstable power balance between the positive and negative resistances, and sustained by the inductor and capacitors. The circuit heart is a nonlinear, negative resistor, the resistance curve of which has kinks, or break points, that provide the nonlinearity that causes the oscillations to be chaotic [above left]. In the double-scroll strange attractor of Chua's circuit, the uncontrolled system is shown in red and the effect of applying derivative control, in blue. The circuit goes from a chaotic state to its non-oscillating steady state after a short transient.

tional to the difference between the first peak and the current that flows at the period-1 fixed point. In the OGY method, on the other hand, the correction is carefully calculated from information about the system dynamics. This information may be obtained by looking at long strings of data from the system, which of course is avoided by using the OPF technique. In the OPF technique, the control system itself does the search for stable orbits.

There are a few basic steps to calculating the corrections with analog electronics. First, a current peak is compared to the desired set-point current peak. If the difference is less than a value determined by a window comparator, an error signal proportional to this difference is generated. The error signal is used to modulate some parameter of the system. In the case of the diode resonator, the error signal modulates the signal generator amplitude for one period. If the difference lies outside the window, the error signal is zero. The set point, window, and gain are adjustable.

Using this stabilization technique, many periodic orbits were controlled in the diode resonator. The period-1 orbit in the diode resonator appears in the double exposure photo in Fig. 2, bottom, where the uncontrolled return map is shown just prior to control initiation, and the stabilized period-1 orbit is the bright dot.

A unique feature of the OPF method is the stabilization of high-period orbits. For example, in the diode resonator, we have controlled orbits that last as long as 23 voltage-drive cycles. Several corrections were made during these long orbits, since otherwise the sensitive nature of chaos would not allow them to stabilize.

Controlling high-period orbits may prove useful as more applications are developed. The appeal of such an orbit is that it visits all different states of a system, or regions of the attractor—as would a chaotic orbit—yet it is completely predictable. For instance, a desirable weather pattern would need plenty of variety and at the same time be predictable for tomorrow and even next week. Admittedly this is an unrealistic example; however, it demonstrates that not all systems are best suited for a period-1 orbit. A high-period orbit in the diode resonator circuit is shown in Fig. 6.

POWERFUL CONTROL. Rajarshi Roy and his students at the Georgia Institute of Technology, Atlanta, also had a fast (very short period) system they wished to control. Their system consisted of a neodymium-yttrium-aluminum-garnate (Nd:YAlG) laser and a frequency-doubling crystal. At high levels of input power, the intensity of the laser's output power fluctuates chaotically.

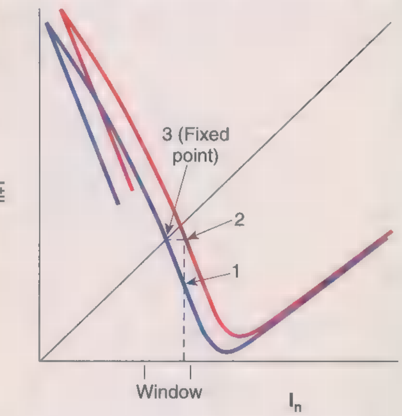
The OGY method required too much calculation time as the intensity fluctuated as fast as 150 kHz. Furthermore, the researchers did not know some of the details about their system necessary to employ OGY. OPF, on the other hand, being a trial-and-error method, fit their needs nicely.

The group used an independent generator to supply a synchronizing signal for the OPF control circuit. This signal tells the controller when to sample the laser intensity. Roy and his students found that when this signal is very close to the natural frequency of the chaotic oscillations, the previously chaotic signal would become locked to the sync signal. By using these findings and techniques, the group was able to control the laser into many periodic orbits, up to period-9.

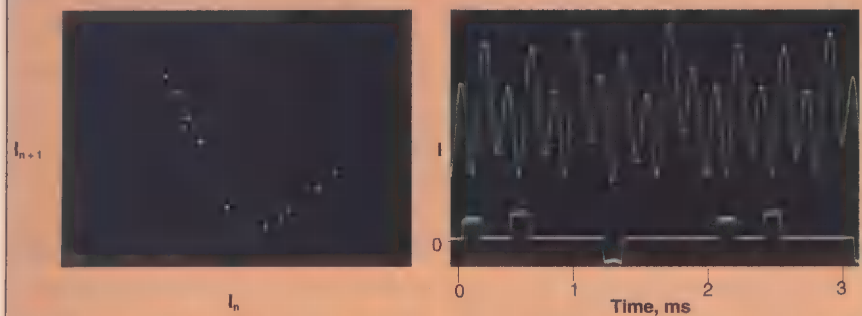
One serendipitous finding was the suitability of the same method for controlling the nonoscillating intensity of the laser's output. The laser starts to oscillate only at high input power; at low power the intensity is constant. Fluctuating power output is generally undesirable, so quenching these oscillations can be rather important.

The strategy is to put the laser in the constant intensity state and turn on the controller. Adjusting the offset of the controller adjusts the feedback signal to zero. Then, if the input power is raised and the feedback signal kept as small as possible, the steady output can be increased to levels at which the intensity of the light beam would otherwise be fluctuating chaotically. The final results were that the range of steady output was increased from about 20 percent above lasing threshold to more than 300 percent above threshold.

These remarkable findings led us to apply the control circuit to a simple nondriven electronic circuit. The dynamics of Chua's circuit are strikingly similar to those of the laser, so it made an ideal choice. Since there is no drive, we had to somehow perturb one



[5] In this return map of the diode resonator, the two curves represent the attractor at two drive voltages. A period-1 orbit at the drive voltage of the blue attractor is desired. To stabilize this orbit, the current is measured at 1, and immediately the drive to the red attractor is increased so the current is at 2. Note that the currents 1 and 2 are the same, but have different values of I_{n+1}. From 2, the value of I_{n+1} is exactly at the period-1 fixed point of the blue attractor. The drive returns to normal, and the system naturally flows toward the fixed point of the original attractor where $I_{n+1}=I_n$, denoted 3.



[6] The return map depicts a period-11 orbit, stabilized with the OPF method. The current in the diode resonator during the orbit is shown in the top trace and the feedback control signal is the lower trace.

of the circuit elements. So we made the negative resistance into a parallel combination of fixed and voltage-variable resistors. The feedback signal is applied to the variable resistance so that the overall negative resistance is controlled by the OPF circuit.

Varying the negative resistance of Chua's circuit has the same effect as changing the drive voltage in the diode resonator, namely, it moves the return map of the system along the diagonal. Following Roy, we used an independent sync signal to lock onto the periodic orbits. Again, low- and high-period orbits were stabilized, and the steady state was also controlled in the chaotic regime.

A group of French researchers, S. Bielawski, M. Bouazaoui, D. Derozier, and P. Glorieux of the Laboratory of Hertzian Spectroscopy at at the Université des Sciences et Techniques de Lille, Flandres-Artois, at Villeneuve d'Ascq, pointed out that an easier way to stabilize the steady state is to feed back the derivative of the detected output to the drive parameter. They showed this more traditional method works well on their optical-fiber laser system. The idea is to continuously feed back into the pump diode a current that is proportional to the time derivative of the output intensity. Then the intensity moves to a single, constant level, and the control signal approaches zero.

To demonstrate, the same method was applied to Chua's circuit. The blue trajectory in Fig. 4, bottom right, shows what happens once the control is switched on. After a short transient, the chaotic voltage spirals into the steady-state fixed point.

The above are examples of suppressing a bifurcation in autonomous systems in which the oscillations appear when the steady state becomes unsteady. This kind of bifurcation can also be suppressed in driven, quasi-periodic systems. The double-diode resonator circuit first undergoes a period-doubling bifurcation, then a bifurcation into the quasi-periodic state. Using the OPF procedure outlined above, we can increase the drive and keep the system in the period-doubled state far beyond drive levels where the quasi-periodicity and chaos usually occur.

CHAOS AND YOU. These techniques for controlling chaos have been referred to as clever solutions in need of good problems. Aside from the laser, are there any truly useful applications for them?

Ditto and his group were able to control cardiac chaos. They extracted a part of a rabbit heart and made it arrhythmic with an injection of the drug ouabain. The group first showed that the arrhythmia was indeed chaotic and not random. Then they used the OGY method to control it and reassert a regular beat using only small, carefully chosen electrical impulses. Researchers are already working on smart pacemakers that they hope will one day be used on human hearts.

It has been known for years that some chemical reactions become chaotic. Rollins and Showalter and their respective groups at Ohio and West Virginia universities have shown that these chemical reactions can be controlled, allowing the reaction efficiencies to be increased. Future research will include burning processes. For example, every time a rocket is launched, too much of its fuel goes into making a lot of useless noise.

Louis M. Pecora and Thomas L. Carroll at the U.S. Naval Research Laboratory are studying how nonlinear electronic systems respond to chaotic driving signals. They found that two identical but separate systems could give synchronized chaotic signals when driven by a transmitted chaotic signal. This allows for encrypted communications by transmitting two chaotic signals, one a reference and the other modulated by the information signal. Very recently, Scott Hayes of the U.S. Army Research Laboratory, Adelphi, MD, along with Grebogi and Ott, showed that by controlling Chua's circuit into one side or the other of the double-scroll attractor, digital information could be transmitted over a chaotic signal. More recently still, Keven Cuomo and Alan Oppenheim of the Massachusetts Institute of Technology have used synchronized analog chaotic circuits to demonstrate two possible approaches to private communications.

Another intriguing area of future research is in the field of turbulence. It is known that tuna fish can go much faster than a underwater craft of the same size and power. While the fishes' greater efficiency may be due to their wiggly motion, there probably is more to it than that. Objects moving through a fluid create turbulence, which contains energy, and is a complicated form of a chaotic phenomenon. Reducing turbulence by chaos-controlling techniques could increase the fuel economy and performance of aquatic and other vehicles as well.

Given the variety of chaotic systems that have been controlled, some have naturally asked if the weather is a controllable system. Weather, after all, seems to be a chaotic system, is predictable for a while, and is also deterministic, since all the physics is known. It would certainly be beneficial to eliminate extremes like hurricanes.

The problem is that, although chaos is found in many simple systems, it does not follow that every chaotic system has an underlying simplicity that could be exploited. The weather just has too many variables to be modeled accurately. Although perturbations applied by something as small as a butterfly may have a large effect on future weather patterns, to figure out where and when to apply nudges to a weather system will be beyond our reach for quite some time. Besides, who has time to keep track of all those butterflies?

TO PROBE FURTHER. There have been many articles recently on the control of chaos in simple systems. Those specifically related to the control of chaos in electronic circuits include: "Stabilizing High-Period Orbits in a Chaotic System: The Diode Resonator," by Earle R. Hunt, which was published in both *Physical Review Letters*, (Vol. 67, no. 15, Oct. 7, 1991) and *Modern Physics Letters B* (Vol. 6, no. 5); "Dynamical Control of a Chaotic Laser: Experimental Stabilization of a Globally Coupled System," by Rajarshi Roy, Earle Hunt, and others, in *Physical Review Letters*, (Vol. 68, no. 9, March 2, 1992); and "Controlling Chaos in Chua's Circuit," by this article's authors and T. E. Tigner, published in the *Journal of Circuits, Systems and Computers* (Vol. 3, March 1993). A good general reference is Francis C. Moon's *Chaotic and Fractal Dynamics* (John Wiley & Sons, New York, 1992).

One of the first papers in this area was "Controlling Chaos," in *Physical Review Letters* (Vol. 64, no. 11, March 12, 1990). "Using small perturbations to control chaos" was published in *Nature* (June 3, 1993). ◆

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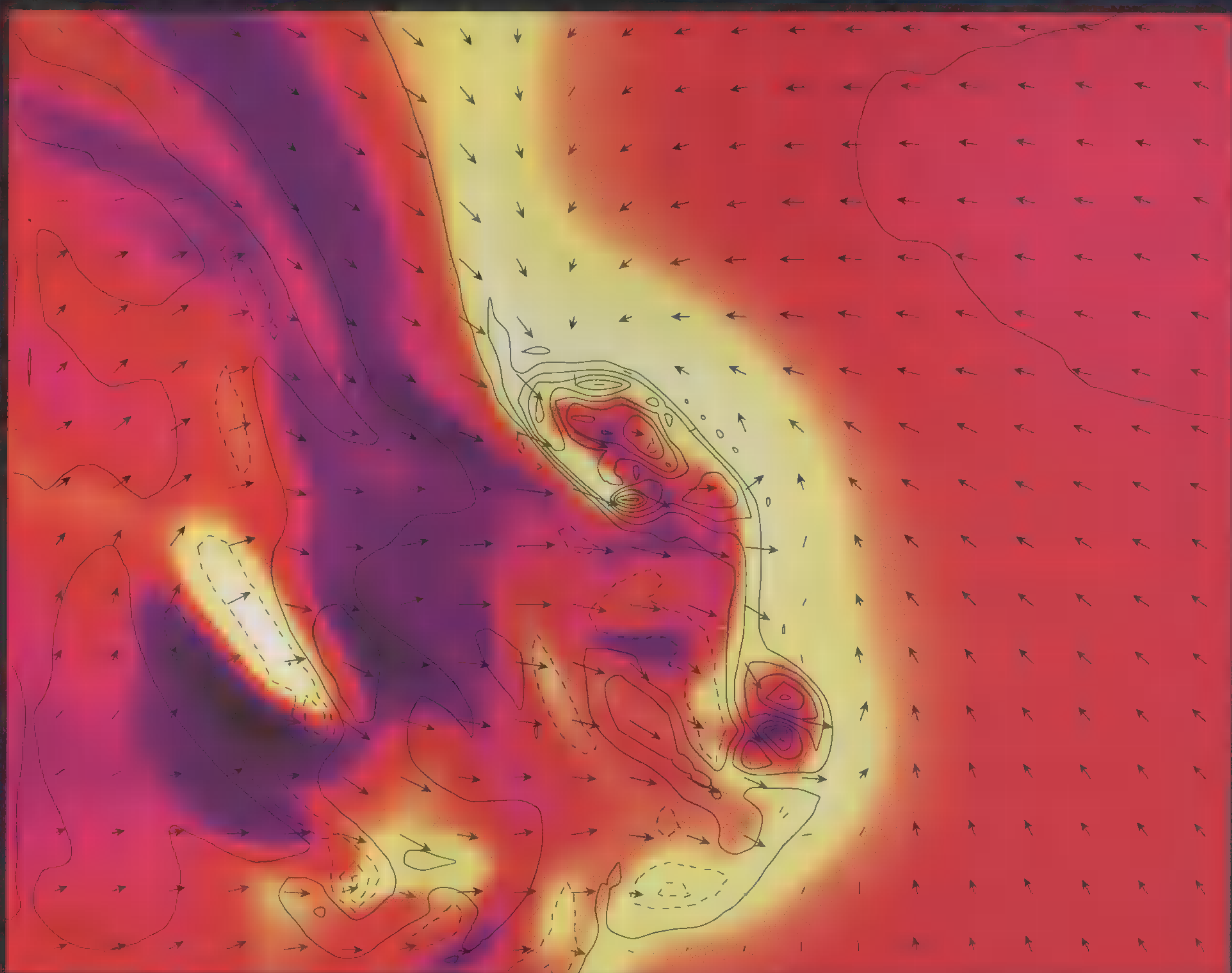
IEEE SPECTRUM

FOCUS REPORT

GUIDE TO MATH, VISUALIZATION AND DATA ACQUISITION SOFTWARE FOR ENGINEERING AND SCIENCE



Math, visualization, and data acquisition

Visual Numerics Inc.

Data visualization software used in magnetic resonance imaging of a human head lets medical imaging experts superimpose the shape of the head on brain scans. Here PV-Wave Advantage by Visual Numerics Inc., Houston, TX, was used.

A designer of flight control systems in a large aerospace company explores two-dimensional patterns of aerodynamic flow around control surfaces of a next-generation aircraft. Elsewhere, an engineer examines test data from the latest version of an automobile engine control system. In yet another laboratory, system planners analyze the load factors of telecommunications networks in different countries and display the results on a map.

Gadi Kaplan Senior Technical Editor

In all these situations, mathematics software tools have been playing an increasingly important role. While many believe that intuition is vital for success in most fields of engineering, there is no denying that math is the backbone by which virtually all designs are supported. At the same time, data acquisition continues to be central to many scientific experiments and to the evaluation and testing of ever more complex system designs.

In this fourth annual *IEEE Spectrum* focus report on software for engineers and scientists, we concentrate on three areas—symbolic and numerical math, data analysis and visualization, and data acquisition.

Altogether, software packages from more than 110 companies—often more than one apiece—are featured in three different tables. Included are older, more established packages as well as newcomers. While we cannot claim that this is a comprehensive list, it is a fair representation of the cream of the crop in these three areas.

In the symbolic and numerical math area there is a clear distinction between packages for exploratory mathematical analysis and those for number crunching—the solution of large or repetitive numerical problems [p. 42]. The growing availability of visualization in data analysis software reflects its groundswell of popularity among engineers and scientists. A noticeable trend is support for MS-Windows by most vendors [p. 60]. Data acquisition software runs the gamut from general-purpose tools to packages tailored to specific data acquisition cards and those with data reduction capabilities [p. 76].

For more information about the packages, readers may circle appropriate inquiry numbers on the reader service card attached to the issue or else contact the vendors directly, using the telephone and fax numbers in the tables.

In the course of researching and writing this issue, it became clear that Internet contributes heavily to the exchange of software packages and general application ideas. Some Internet contacts and other sources are listed in To probe further [p. 87].

Last, but not least, the report editor is grateful for the support of members of the advisory board, assembled for this project.

Cover: A horizontal cross section of a three-dimensional simulation of a thunderstorm shows vertical velocity in color, horizontal velocity as a vector field indicated by arrows, and vorticity as a contour plot. Data came from the National Center for Supercomputing Applications, University of Illinois, Urbana-Champaign. Analysis was performed with Transform 3.0 software by Spyglass Inc., Savoy, IL, which also supplied the photo.

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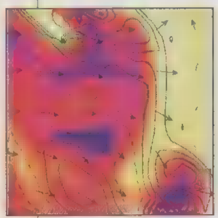
'Abstract' math made practical

Symbolic math software tools do much of the work of engineering analysis and design



Specialized programs are the best solution for many engineering tasks, such as designing antennas or modeling circuits. But often none is available or suitable or inexpensive enough for tasks like the exploratory analysis of data, developing new algorithms for signal analysis, or the theoretical analysis of a whole host of engineering applications.

That situation is changing. A wide variety of mathematics programs now carries out such tasks quickly and efficiently, and the field is evolving rapidly, in part because of the growing power of personal and other computers, and in part because software designers are incorporating graphical user-interfaces (GUIs) and other user-friendly elements. Moreover, vendors are developing joint ventures with traditional book publishers that target products for large educational and engineering markets.

Kenneth R. Foster University of Pennsylvania

Commercial programs for mathematical analysis may include numerical or symbolic capabilities. (Symbolic math programs, also known as computer algebra programs, can find exact analytical solutions to mathematical problems of many kinds, such as the solution of differential equations and the evaluation of integrals.) As a group, math programs are diverse, but large subgroups can be identified, depending on how they are principally used.

EXPLORING OR CRUNCHING. One key application is exploratory math analysis, which may include investigating data, developing algorithms, or solving one-of-a-kind math problems. Programs for this include high-end packages like Mathematica, Macsyma, or Maple [see table]. Though programs in this group combine many functions (in some cases over 1000), they are often poorly suited for large or repetitive numerical calculations because of their slow response and several other inefficiencies.

A quite different need is for number crunching, that is, for solving large or repetitive numerical problems or visualizing masses of data. Requirements for these jobs are computational speed and the ability to manage and display great quantities of numerical data. Examples may include fitting data to a theoretical function or digital signal analysis. Such matrix-based programs as Gauss, Matlab, MLAB, and Xmath are particularly useful since they combine fast calculations on vectors or matrices with powerful programming capabilities, and they come bundled with many engineering programs.

For very large numerical calculations, a user would probably turn to specialized math or statistical routines like those sold by the Numerical Algorithms Group (NAG), Downers Grove, IL, and other vendors. Senac, an extensive numerical and algebraic package from the United Kingdom, has added finite element modeling and an interface to NAG's numerical algorithms library.

However, the category of math programs is broad and many of those listed in the table carry out specialized tasks with particular efficiency. These include simulating linear and nonlinear systems (like VisSim) or solving sets of coupled linear or nonlinear algebraic equations (like TK Solver 2.0). This last is shipped with many application files, and has evolved into a general-purpose math package as well.

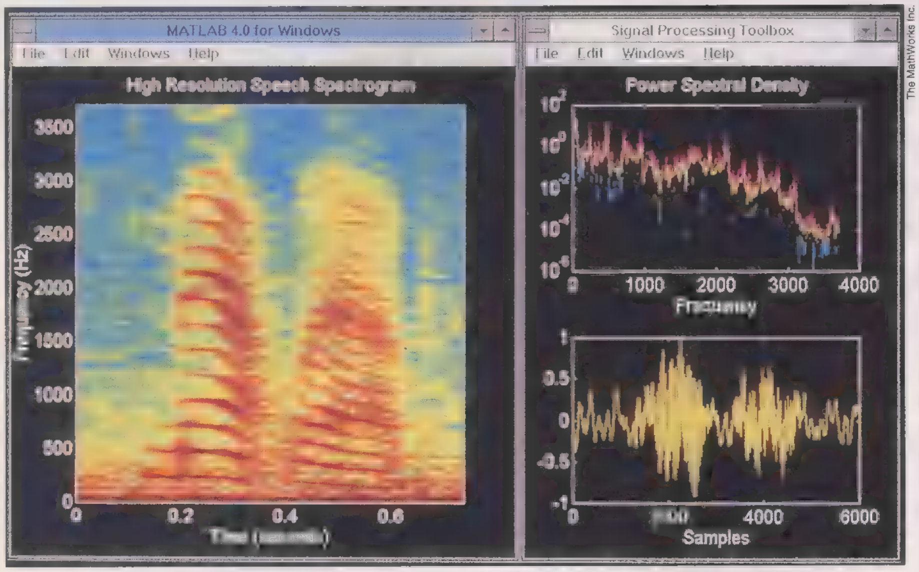
GENERAL MATH. Several math packages, oriented toward number crunching or exploratory math, dominate the market. Their appeal to the engineer lies partly in the many application programs that come with them or that can be purchased separately. Several of these programs run on almost any platform and operating system that an engineer might use. An engineer may begin a project on one platform and move it readily to another, perhaps faster, platform as needed.

The commercial market for computer algebra systems has been dominated by competition between two high-end packages, Maple and Mathematica. Maple's vendor, Waterloo Maple Software Inc., recently issued a major update, Maple V Release 2. (Waterloo Maple Software recently merged with Prescience Corp., the maker of Theorist, a popular math package for the Macintosh.)

Three updates—one major and two minor—of Mathematica have also been done within the past 18 months by its vendor, Wolfram Research Inc. Mathematica has a large collection of application packages of interest to engineers distributed free of charge on the Internet [see "Math software and the Internet," p. 58]

Other strong computer algebra products include Macsyma, one of the original, and probably still the most comprehensive, symbolic math programs, which is making a

(Continued on p. 54)



The MathWorks Inc.

Powerful numerical computations were carried out to illustrate a speech signal's spectrogram [left window] and the sampled signal and its power spectral density [right window]. The software used was Matlab 4.0 by The MathWorks Inc.

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Symbolic and numerical math packages

Product and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Aptech Systems Inc., Maple Valley, WA; 206-432-7855; fax, 206-432-7832					
Gauss 3.1 Unix workstations: $1995+ IBM PC: $995+ **Gauss Light 3.1** Unix workstations: $295 IBM PC: $150 Circle No. 251	IBM PC: 386/486 Unix: IBM RS/6000; HP 9000 700/800; Sun Sparc; SGI	[IBM PC] math coprocessor; 4 MB of free disk space; 4 MB of RAM; [Unix] call	Does mathematical analysis complete with high-quality 2- and 3-D graphics, over 400 analysis functions, and a matrix-based programming language with debugger; is a comprehensive environment for data manipulation, analysis, and visualization	Linear algebra functions; improved user interface with source-level debugger; updated optional modules for simulation, statistical analysis, and more; windowed applications toolkit added to Unix version	Application areas include engineering, physical sciences, biometrics, behavioral sciences, statistics, and econometrics; Gauss Light 3.1 is the entry-level version
The Athena Group Inc., Gainesville, FL; 800-741-7440; 904-371-2567; fax, 904-373-5182					
Siglab for Windows $199 Circle No. 252	PC compatibles	MS-DOS 5.0 or later, 2 MB of disk space, 2 MB of RAM	Provides analysis and display tools for signals and systems (1- and 2-D); simulates complex systems and tests designs using embedded and/or user-defined math and DSP functions	Windows release; new display features and options; OLE 2.0 support	Math analysis and display environment with native rapid-prototype–development language
Bimillennium Corp., Los Gatos, CA; 800-800-8662; 408-354-7511; fax, 408-354-4388					
HiQ Mac: $995 Sun: $3995 (network); $2495 (node-locked) Circle No. 253	Mac: 68020 CPU with math coprocessor Sun: Sparc or compatible	[Mac] System 6.05 (System 7 compatible), 5 MB of disk space, 5 MB of RAM; [Sun] Solaris 1.x, Open Windows 3.0, 10 MB of disk space, 12 MB of RAM	Provides tools for practical mathematics solutions; presents data in graphical, written, and compiled formats	On-page editing; "compiled script" symbol type; text, graphics, and postscript file paste-up ability	Customized data, text and graphics routines for organization, communication, and display of data and results
Boeing Co., Seattle, WA; 800-426-1443; 206-865-3622; fax, 206-865-2966					
Easy5x Engineering Analysis Software $8900 Circle No.254	DECstation, HP, HP-Apollo, IBM RS/6000, SGI, Sun	Unix, X Window Version X11R64, Fortran 77 or C compiler, 20 MB of disk space, 16 MB of RAM	Can simulate/analyze nonlinear dynamic systems and multi-rate sampled-data controllers; design/analyze control system; performs steady-state analysis; simulates highly discontinuous dynamics in stiff systems; runs models in real time; models environmental control systems with predefined components, and other mechanical, electrical, and chemical systems	Hydraulic component library; real-time simulation; vapor-cycle library	Automatically generates source code and sorts equations to form explicit models; has complete GUI
Civilized Software Inc., Bethesda, MD; 301-652-4714; toll-free, 800-6PC-MLAB; fax, 301-656-1069					
MLAB IBM PC: $1495; extended memory version, $1995; **SLAB** IBM PC: $995 Mac: $1495 Sun, NeXT and SGI: $2995 Circle No. 255	IBM PC: 286 or better, wi. math coprocessor; Mac: math coprocessor; Sun: Sparc; NeXT Machine; SGI: MIPS machines	[IBM PC 286 or 386] MS-DOS 3.1 or later; 2.5 MB of disk space; [IBM PC 486 or NeXT machine] NeXTstep 3.0 or later; [Sun] Open Windows or SunOS 4.1 and X11R4 or later; [SGI] Irix with X11R4 or later	Mathematical and statistical modeling system that includes stiff differential equation solving, nonlinear curve fitting with algebraic and differential equation models, matrix and linear algebra computation, signal analysis, statistics, cluster analysis, splines, and high-quality 2- and 3-D graphics	Extended memory support; statistical power and sample-size functions; 3-D hidden-surface graphics	General root finder; manual or automatic control for solving ordinary differential equations; symbolic differentiation used for gradients, Jacobians, and Hessians; limited-life trial version for $100; SLAB stands for streamlined MLAB
Eighteen Eight Laboratories, Boulder City, NV; 800-888-1119, 702-294-1051; fax, 702-294-2611					
PL2500 $2495–$5995 Circle No. 256	ISA Bus	MS-DOS 3.0 or later; MS-Windows 3.0 or later	Library of over 600 functions for use in C, Fortran, or Pascal programs; comes with hardware accelerator	Interface to data-acquisition cards such at Video Frame Grabbers and AD-DA cards	Ideal for large arrays, vectors, matrices of floating-point numbers or integers of real or complex
Fort Pond Research, Acton, MA; 508-263-9692; e-mail, aljabr@fpr.com					
ALJABR 1.5 Mac: $249 SGI: $500 Sun: $500 Circle No. 257	Mac: all SGI: Irix 3.31 or better Sun: Sparc 4.X	[Mac] at least 4 MB of RAM, at least 5 MB of RAM for System 7	General-purpose mathematics package that includes symbolic and numerical capabilities and graphics	On-line and hard copy	Programming and debugging tools allow user to create own packages; educational discounts, licenses
Harmonic Software, Seattle, WA; 206-367-8742					
O-Matrix $95 (educational discounts; license incl. updates) Circle No. 258	IBM PC-compatible: 286 or better	MS-DOS of 3.3 or later, at least 3 MB of disk space	Matrix-based general math program	New product	Like an enhanced Matlab; accepts six matrix types (character, integer, real, double-precision, complex, logical); debugging environment with many error messages
Hyperception Inc., Dallas, TX; 214-343-8525; fax, 214-343-2457					
Hypersignal for Windows Block Diagram V 2.0 $1995 Circle No. 259	IBM PC: 386 or better	DOS 3.1 or later, Windows 3.1, 5.4 MB of disk space (plus space for data files), 4 MB of RAM	Icon-based environment for programming equations and algorithms visually; basic math and advanced signal-processing function libraries are included	Lets user define blocks, hierarchical structures; provides C code generator option	User expandability; allows user to go directly from concept to implementation
Integrated Systems Inc., Santa Clara, CA; 408-980-1500; fax, 408-980-0400					
System Build 4.0 Single-user license: $8000 Circle No. 260	Unix and VMS workstations	DECstation, HP 700 Series, IBM RS/6000, SGI, Irix, Sun Sparcstations	Graphical modeling and simulation of nonlinear dynamical systems	Integration with the Xmath analysis environments; modeling of state-change events	Code generation, document generation, fuzzy logic, and system block options

Symbolic and numerical math packages *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Integrated Systems Inc., Santa Clara, CA; 408-980-1500; fax, 408-980-0400					
Xmath 4.0 Single-user license: $2495 Circle No. 261	As above	As above, plus VAXstations	Mathematical analysis, graphics, and scripting environment	Fully programmable GUI; interactive 2- and 3-D color graphics	Motif user interface; on-line hypertext help system; interactive script debugging provided
Macsyma Inc., Arlington, MA; 800-622-7962; 617-646-4550; fax, 617-646-3161					
Macsyma IBM PC: $349 (acad. $299) Workst.: $999 (acad., $699) Circle No. 262	IBM PC: 386, 387, or 486DX; most workstations—VAX, VMS, Ultrix	[IBM PC] MS-DOS 5.0 or 6.0, Windows 3.1, 15 MB of disk space, [redacted] MB of RAM, 16 MB of paging file; [workstations] 30 MB of disk space, 16 MB of RAM	High-end math package with extensive symbolic math capabilities, 2- and 3-D graphics	Notebook documents using Windows; three times as fast as the previous version; fancy display of math expressions; enhanced graphics viewer	Generates entire Fortran and C programs; vector and tensor calculus; strong Laplace transforms; very reliable symbolic math
The Mathworks Inc., Natick, MA; 508-653-1415; fax, 508-653-6284					
Matlab 4.0 PC and Mac: $1695+ (educational discount) Circle No. 263	DEC, HP, IBM, SGI, Sun workstations and servers; IBM PC, Compaq, or compatible w. Intel 386, 486, Pentium; Mac	20 MB of disk space, 16 MB of RAM	Matrix-based numerical package, [redacted] comprehensive system for interactive computation, 2- and 3-D visualization, modeling and algorithm development; application toolboxes available for special functions	Scientific visualization and imaging capability; GUI development tools; introduction of symbolic math, image-processing, and statistics toolboxes	High-level language has over 500 numeric and graphical functions; includes platform-independent GUI development tools; many application files and news group available through Internet
Matlab Symbolic Math Toolbox PC and Mac: $495+ (educational discount) Circle No. 264	As above	As above, plus additional 10 MB of disk space	An extension of Matlab; an intuitive environment for symbolic computation; fully integrated with Matlab's numerical processing capabilities	A new product; integration of high-accuracy symbolic mathematics with numeric computation	Symbolic toolbox includes full Maple core library and linear algebra package; extended symbolic toolbox provides access to full Maple functionality
Mathsoft Inc., Cambridge, MA; 800-628-4223; 617-577-1017; fax, 617-577-8829					
Mathcad IBM PC, Mac: $495 Circle No. 265	IBM PC: 386 or better, Windows 3.1 Mac: various, incl. Quadra 6.05 or later	[IBM PC] 7 MB of disk space, 4 MB of RAM; [Mac] 6 MB of RAM	Easy-to-use math package that combines numerical and symbolic calculations, graphics, and text in a document	—	Incorporates a subset of the computer algebra program Maple
Mitchell & Gauthier Associates Inc., Concord, MA; 508-369-5115; fax, 508-369-0013					
ACSL/Graphic Modeller $4000–$16 000 Circle No. 266	Sun, HP, IBM RS/6000, SGI	Sun-OS, Solaris, HP UX, IBM AIX, Silicon Graphics Irix	Brings true graphic modeling to simulation; allows simulating complex nonlinear, continuous, discrete, and hybrid systems	Integrated with ACSL runtime; tools include Powerblock (for simpler simulation) and Powerguide (for building a valid model)	Frees the user from burdensome programming details
Numerical Algorithms Group Inc., Downers Grove, IL; 708-971-2337; fax, 708-971-2706					
Axiom 2.0 $995+ Circle No. 267	IBM RS/6000, Sun Sparc, other Unix	80 MB of disk space, 32 MB of RAM	A knowledge-based, object-oriented mathematical language for solving computational problems symbolically, numerically, or visually	Improved on-line user's guide with complete, customizable templates; extra point-and-click graphics-control panel features for high-resolution output in various 3-D, solid-fill modes	Internal hierarchical mathematical knowledge-base sets; solves higher orders of difficult problems; also lets users seamlessly write their own extensions to Axiom for custom functions or data types
Prescience Corp., San Francisco, CA; 415-543-2252; fax, 415-882-0530					
Theorist 1.5 $289.95 Circle No. 268	Mac	System 6.05 or later; 1.5 MB of disk space, 1 MB of RAM	A WYSIWYG symbolic math and graphing program for solving and graphing equations; creates 2- and 3-D graphics that can be easily manipulated and animated	Tables (real and imaginary); Fourier transforms; more plotting options (scatter, implicit, and 3-D parametric); QuickTime movies, etc.	Easy to use; true mathematical display of both input and results
Expressionist 3.1 $159 Circle No. 269	Mac, Windows	[Mac] System 6.05 or later; 1 MB of RAM; [Windows] 3.0 or later, 2 MB of RAM, [redacted] mouse is recommended	Provides typeset math equations	Simplified palette with editing tools arranged as buttons/icons; color and rotation abilities; improved file conversion in 3.1	Automatic and flexible spacing, editing of equations from within the word document using EGO or OLE
Quantitative Technology Corp., Beaverton, OR; 503-626-3081; fax, 503-641-6012					
PC Advantage PC version (price not listed) Circle No. 270	IBM PC: 386 or better	MS-DOS 5.0 or later, Windows 5.1, 10 MB of disk space, 2 MB of RAM	A comprehensive math library; signal processing, curve fitting, numerical integration, and differentiation and matrix library included	—	Available in C; written in ANSI C; comes with test tools

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Quantitative Technology Corp., Beaverton, OR; 503-626-3081; fax, 503-641-6012					
QTC Extended-Precision Intrinsics Many architectures, prices Circle No. 271	PCs through Cray	—	Extended-precision math package that provides up to 512 binary bits for the common transcendental functions	—	C source can be modified; self-installation; end usage documentation; tools to test algorithms
QTC IEEE - Emulation Library As above Circle No. 272	Supercomputers, workstations, and mainframes	—	Provides basic arithmetic operations and conversion routines	—	Coded in C; usage and installation documentation; compliant with the IEEE-754 standard
Spec Advantage As above Circle No. 273	Workstations, supercomputers, and PCs	[IBM PC] MS-DOS, OS/2; Unix; Borland or Microsoft for the PC	A comprehensive library of special functions, including probability distribution; trigonometric, hyperbolic, and exponential integrals; gamma, factorial, Bessel, Kelvin, and error functions	—	In C or Fortran; object and source code for 20+ hosts; includes single- and double-precision floating-point libraries
Stat Advantage As above Circle No. 274	Supercomputers through PCs	[IBM PC] DOS, OS/2, and Unix	High-performance library; includes algorithms for statistical analysis	—	—
Rogue Wave Software Inc., Corvallis, OR; 800-487-3217; fax, 503-757-6650					
Lapack.h++ DOS version: $599 Others: $795 Circle No. 275	IBM PC: MS-DOS, Windows, OS/2, Unix	C++ compiler	Intuitive, object-oriented (C++) interface to the entities and algorithms used in linear algebra	First release out in mid-September, 1993; includes source code; complete test suite available	Includes Math.h++, a toolbox of powerful C++ types for numerical programming; discounts available
Signal Technology Inc., Santa Barbara, CA; 805-899-8300; fax, 805-899-4344					
N!Power Family Developer: $5K–$15K **First!Power:** $2K–$3K (both permanent licences) Circle No. 276	Sun Sparc, HP 9000/7xx, DECstation, VAXstation, X-Windows server	25 MB of disk space, 16 MB of RAM; X-Windows systems; OpenWindow or HPVue or Motif X toolkit	Customizable, extendable framework for interactive numerical analysis, simulation, and block diagram modeling; based on IEEE Scheme language; optional modules available for DSP, acoustics, and communications	Added CGM, PICT graphics file output; improved color/graphics tools; added matrix operations	Object-oriented algorithm and graphic development; users can add high-level symbolic functions to block diagrams; developer version may be leased for $2.5K; OEM prices

Symbolic and numerical math packages *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
SLP SA, Paris, France; (33 +1) 4521 9595; fax, (33 +1) 4521 9029; in the United States, contact SciTech at: 800-622-3345; fax, 312-472-0472					
STATlab 7600 FF in France, US $695 elsewhere **GEOlab** 2500 FF, $295 elsewhere Circle No. 277	MS-Windows	4 MB of RAM, 2 MB of disk space	Graphical exploration and analysis of data under Windows; brushing tools, zoom, hypertext help; unlimited file sizes; data dictionary available for flexible data management (includes descriptive statistics, regression, correlation, contingency tables, many tests, principal components, correspondence, factor, and discriminant analysis); over 60 graph types	U.S. English version; factor analysis; multiple regression; image processing and mapping (GLS)	No limit on size of file STATlab routines can analyze; the program has many interactive graphical data manipulation tools
Soft Warehouse Inc., Honolulu, HI; 808-734-5801; fax, 808-735-1105					
Derive 2.58 $250 Circle No. 278	IBM PC, XT, AT, or compatible	[IBM PC] MS-DOS 2.1 or later with ≥ 512-kB memory;[palmtop] HP 95 or 100LX or other PC-compatible ROM card computer: 512-kB memory	Menu-driven symbolic math for algebra, trigonometry, calculus, and matrix algebra and for plotting the results	Has commands that import, analyze, and plot raw numeric data files from other programs; automatic solver for first- and second-order differential equations	User-friendly algebra program with menu-driven user interface; with new version, Derive screen images are easy to print or store as TIFF files
Derive XM 2.58 $375 Circle No. 279	IBM PC: 386 or later	As above	Symbolic math for large, complicated problems in algebra, trigonometry, calculus, and matrix algebra	As above	Uses extended memory for problems requiring up to 4 GB; with new version, Derive screen images are easy to print or store as TIFF files
Statistical Sciences (StatSci), a division of Mathsoft Inc., Seattle, WA; 800-569-0123, 206-283-8802; fax, 206-283-8691					
S-PLUS 3.1 Windows version: $1200 (stand-alone) Unix version: $2800 (discounts) Circle No. 280	DECstation, HP 9000 300/400/700/800; IBM PC or compatible 386 or later with math coprocessor; IRIS; Sun Sparc	[PC] Microsoft Windows 3.1 or later, 8 MB of RAM, 20–25 MB of disk space; [Unix] 12 MB of RAM, 45 MB of disk space	An interactive environment with graphical data analysis and an object-oriented language; suitable for exploratory data analysis graphics, statistics, and math; can serve as an application package or as a development environment for custom data analysis and graphics	Improved performance and memory utilization; new computational functions, new functions for statistics, enhanced modeling capabilities	Useful for academic research and instruction, health research, analysis of quality data in manufacturing, financial market trend analysis, modeling of communications networks, and more
Techni-Soft, Livermore, CA; 510-443-7213; fax, 510-743-1145					
SSPACK–PC 2.0 IBM PC, Mac: $995–$1245 Sun: $2995–$3745 (university discounts) Circle No. 281	IBM PC: 386 or later Mac: IIci or better	Runs under Matlab 4.0, 3.5, 1 MB of disk space	Model-based signal processing using UD-Kalman filter algorithms for linear time-varying and nonlinear processes or signals	Ported under Matlab 4.0; time-varying linear system option; nonlinear system simulation and estimation using extended UD-Kalman filter	New push-button menu system with enhanced color graphics; UD factorized matrix techniques yield highly stable numerical solutions
SSPACK 3.0 Sun: $4K–$5K Mainframe: $6000–$7200 (univ. discounts) Circle No. 282	DECstations, HP, IBM RS/6000, SGI, Sun, VAX	VMS, Unix, AIX, Solaris, HP UX Fortran 77, X Window, 5 MB of disk space	As above, plus display and statistical analysis	Pull-down menu processor with interactive graphics environment; advanced statistical operations	Is designed to solve model-based signal processor design and analysis problems
Universal Technical Systems Inc., Rockford, IL; 800-435-7887; fax, 815-963-8884					
TK Solver 2.0 Industry— IBM PC: $595 Mac: $395 Faculty: $89 Circle No. 283	IBM PC 286 or better, Mac, VAX/VMS, Unix	[IBM] 3 MB of disk space, 1 MB of RAM; [Mac] 512 kB + 1.75 MB of disk space, 1.5 MB of RAM	Solves sets of linear, nonlinear, and differential equations forward or backward for any variables of interest; combination of declarative and procedural languages allows for "backsolving" of applications developed in TK Solver	Customizable interface; keystroke macros; expanded math and statistics library (over 200 tools and examples)	Version for student or home use available for $49
University of London Computer Centre, United Kingdom; (44+71) 405 8400, (44+71) 242 1845					
Senac V5.0 £ 300–£ 1200, excluding VAT (volume discounts for universities) Circle No. 284	Sun Sparc (OS 4.x, Solaris 2.1); DEC Alpha and VAX/VMS (OS 5.x); others include Cray, HP, and SGI	40 MB of disk space, 30 MB of RAM; Fortran compiler; NAG libraries	A large modular software system that ties numeric, symbolic, and graphical capabilities, along with knowledge-based interfaces, to certified numerical libraries	Finite-element modeling, discrete and global optimization, interface to complete NAG library, and built-in numerical analysis routines from numerical recipes	Package includes full user and system support; Microsoft Windows object-oriented version—with a GUI—will be available for Q1 1994
University of Sydney, Sydney, NSW, Australia; (61+2) 692 3338; fax, (61+2) 692 4534					
Magma 1.0 US $400–$4000, depending on machine Circle No. 285	Any Unix workstation, Mac with A/UX 2.01 or higher	—	An integrated system for solving hard computational problems in algebra (groups, rings, fields, modules, and more) and such combinational structures as graphs and codes	A new product	IBM PC 386 and up version in preparation; a kernel in C has efficient implementations of chief algorithms; contains almost all the algorithms in the CayLay System
Visual Numerics Inc., Houston, TX; 800-222-4675; fax, 713-781-9260					
C Numerical Libraries $4750 Circle No. 286	DEC, HP, IBM, SGI, Sun workstations and mainframes	32.5 MB of disk space, RAM dependent on application	More than 220 math and statistics functions for speeding the building of numerical analysis applications in C	On-line documentation; flexible leasing options	Reduces application development time by up to 95% by reducing the amount of code required

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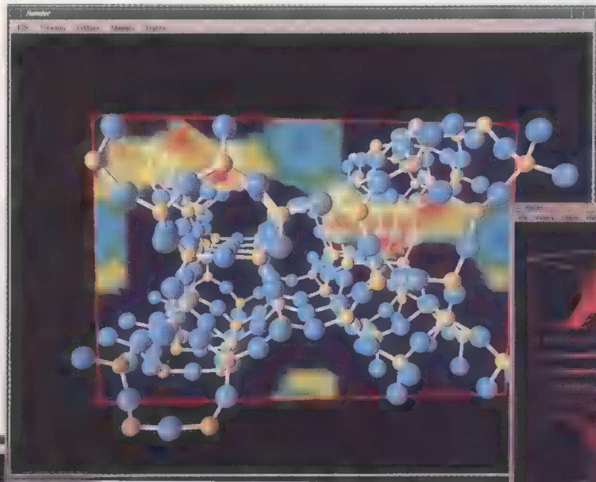

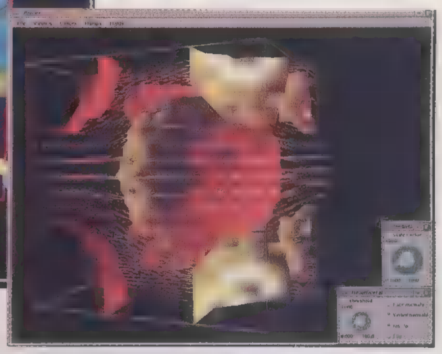

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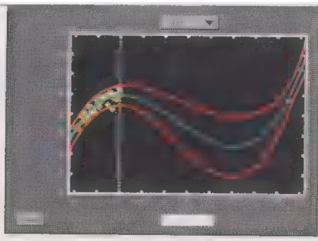

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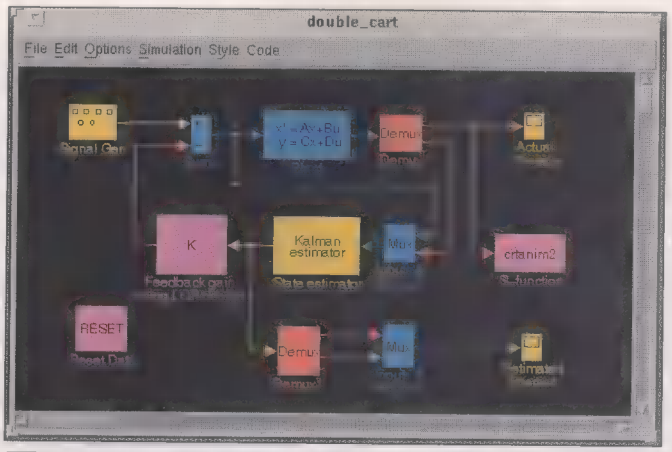

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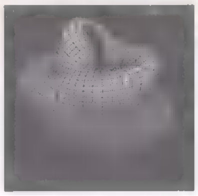

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- ❑ Symbolic Math Toolbox (new)
- ❑ Statistics Toolbox (new)
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- ❑ Model Predictive Control Toolbox (new)

Computer Platform – check all that apply:

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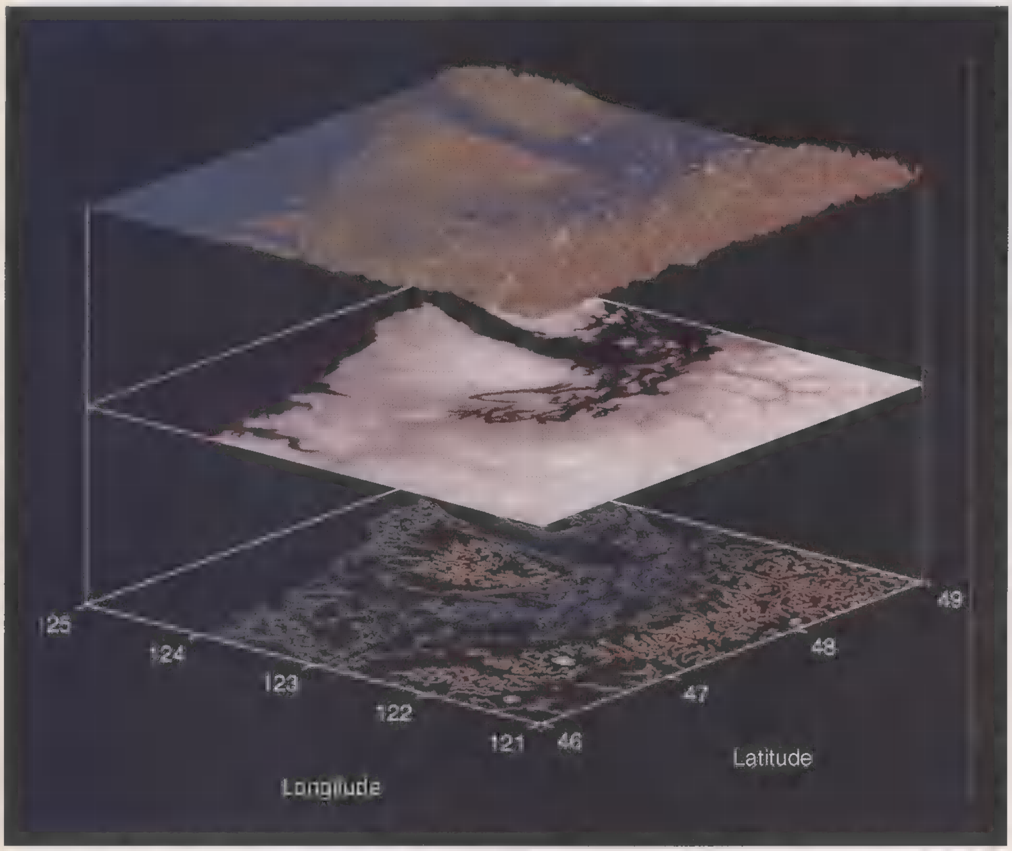

Altitude data of the Puget Sound region of the United States and Canada. Data was enhanced with the Image Processing Toolbox and rendered with MATLAB Handle Graphics. Data courtesy of NOAA.

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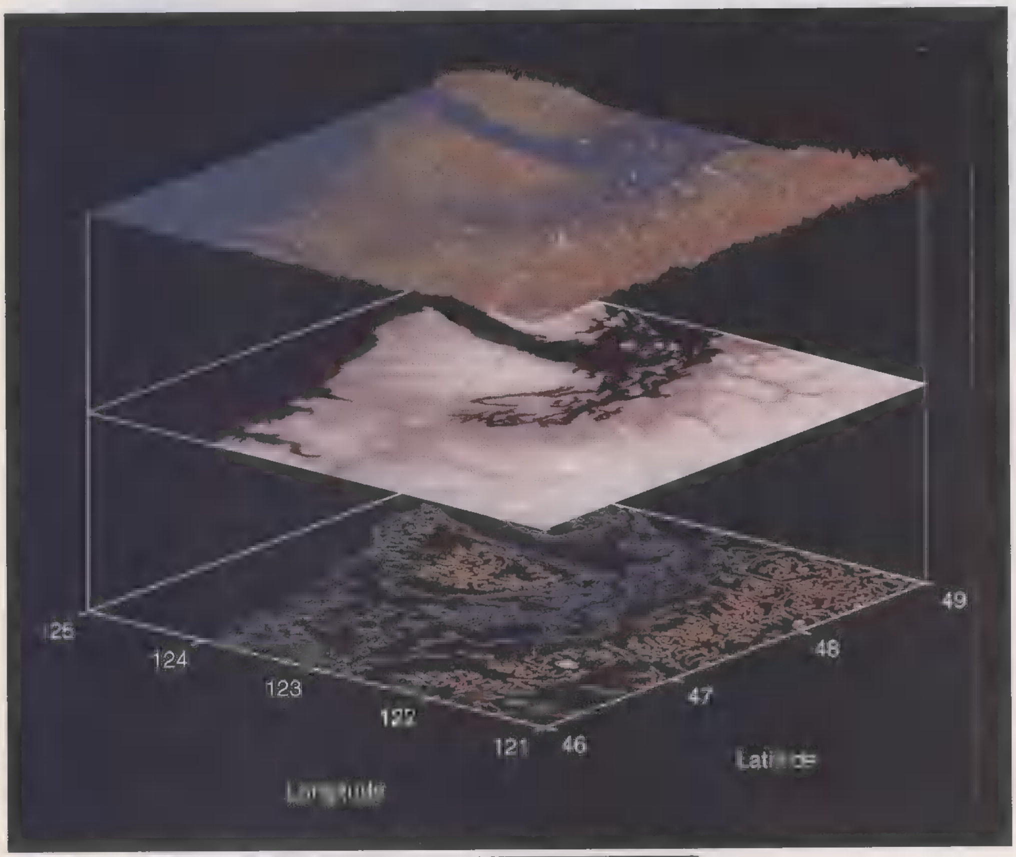

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Symbolic and numerical math packages *(continued)*

Product and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Visual Numerics Inc., Houston, TX; 800-222-4675; fax, 713-781-9260					
Fortran Numerical Libraries $5250 Circle No. 287	Sun, HP, DEC, SGI, and IBM workstations and main-frames	38 MB of disk space, RAM dependent on application	Over 450 user-callable math and statistics functions for speeding the building of numerical analysis applications in Fortran	On-line documentation; flexible licensing options	As above
Vanguard Software Corp., Smithtown, NY; 800-538-8173; fax, 516-979-6829					
HyperCalc 2.0 $195 Circle No. 288	IBM PC/XT, AT, PS/2 or compatible	MS-DOS 2.0 or later, graphics card, hard disk, 640 kB of RAM	Assists in decision support analysis using mathematical and logical models; combines features of artificial intelligence and math applications	Virtual memory support; improved hierarchical tree editor; 3-D graphing	Supports units of measure in all calculations; can be expanded with user-defined library models
Visual Solutions Inc., Westford, MA; 508-392-0100; fax, 508-692-3102					
MathViews $295–$995, depending on matrix sizes Circle No. 289	IBM PC: 389, 486 or compatible	MS-Windows 3.1, 2 MB of disk space, 4 MB of RAM, 1.2- or 1.44-MB of floppy	Matlab-compatible, interactive interpreter of M-files for control systems design and for signal processing	Integrated debugger for M-files, 2- and 3-D graphics, DDE and DLL support, and capable of automatic updating of dependent variables	Runs the Matlab 3.5 toolboxes; may be enhanced with M-file toolboxes or user-written DLLs
VisSim Micro: $295 PC: $495 Full: $1495 Circle No. 290	IBM PC 286 or better, Unix/X RISC systems	[IBM PC] MS/Windows 3.X, 1 MB of disk space, 2 MB of RAM, 1.2- or 1.44-MB floppy; [Unix/X] 3 MB of disk space, 8 MB of RAM, floppy-disk drive or 1/4-inch tape	Simulation program for multi-rate, linear and nonlinear, dynamical systems; time-domain analysis of control systems; concurrent static optimization support; neural networks, real-time data acquisition, discrete-event queue simulation available	Support for transfer function blocks, FFT plots and solution of stiff equations	Users specify system via block diagrams; add-ons possible via DLL capability in MS/Windows; Matlab interface possible via VisSim/Analyze; DLL and DDE support; add-ons for C-code generation
Waterloo Maple Software Inc., Waterloo, ON, Canada; 800-267-6583; 519-747-2373; fax, 519-747-5284					
Maple V Release 2 IBM PC , Mac: $395 (introductory price) All other platforms: call Circle No. 291	IBM: 386, 486; Mac: any with System 6.0.7 or better; Unix, Amiga, VMS, and many others	[IBM] MS-DOS or PC-DOS 5.0 or later, MS- Windows 3.1, 10 MB of disk space, 4 MB of RAM	Computer algebra package with extensive symbolics and numerics, graphics, and programming capabilities; solves integrals, differential equations, and systems of equations exactly and numerically	Real math notation; animation; support of computations based on user-defined assumptions, such as "assume x>0"	Uses worksheet-style interface, combining text, graphics, and symbolic calculations in a document; application files available over the Internet
Wolfram Research Inc., Champaign, IL; 800-441-MATH; fax, 217-398-0747					
Mathematica 2.2 IBM PC: $595+ Mac: $595+ Unix: $1995 + Circle No. 292	HP; IBM PC: 386 or better Mac: II, IIcx, IIci, IIfx, IIsi, SE/30 (enhanced version only; others run on any Mac); Sun	[IBM PC] MS-DOS 3.0 or later, Windows, 13 MB of disk space, 6 MB of RAM; [Mac] 6.0.7 or later, A/UX 2.0, System 7.0 or compatible, 6 MB each of disk space, RAM; [Sun] Sun OS 3.5 or later, 22 MB of disk space, 8 MB of RAM; [HP] HP-UX 7.0 or later, Domain/OS; SR 10.1 or later, 24 MB of disk space, 8 MB of RAM	High-end math package with extensive symbolic, graphics, and numerical capabilities	Enhanced equation-solving capabilities, integration routines, graphics packages and statistics routines; over 20 new packages include nonlinear fitting, elliptic integration, and spline fitting	Includes differential-equation solvers (numeric and symbolic), transform packages, communication with external programs; notebook interface; many applications available over Internet; links to spreadsheet and data acquisition programs; many books written about the program; widely adopted in education

ACSL=advanced continuous simulation language; AD/DA=analog-to-digital/digital-to-analog; CGM=Computer Graphics Metafile; DDE=dynamic data exchange; DLL=dynamic-link library; DSP=digital signal processing; EGO=edit graphic object; FFT=fast Fourier transform; GUI=graphical user-interface; HP=Hewlett-Packard workstations; HPGL=Hewlett-Packard Graphics Language; ISA=Instrument Society of America; ISDN=integrated-services digital network; Mac=Macintosh; M-files=files specific to Matlab software; MPEG=Motion Picture Experts Group; NAG=Numerical Algorithms Group; OLE=object linking and embedding; PICT=an image file format; SGI=Silicon Graphics Inc.; SQL=standard (or structured) query language; TIFF=tagged image file format; UD=the factorization of a covariance matrix into upper triangular (U) and diagonal (D) matrices; WYSIWYG=what you see ■ what you get.

'Abstract' math

(Continued from p. 42)
forceful comeback with a rejuvenated vendor, Macsyma Inc. The company has released a new Microsoft Windows version featuring a graphical user-interface and other improvements. Another is Derive, an algebra program for low-end PCs running Microsoft MS-DOS; Derive recently appeared in ■ version that can solve larger problems by using extended memory. And Axiom, ■ large computer algebra program for workstations, has come out with a version for Sun Sparc workstations.

For numerical problems, Matlab (for PCs and many other platforms) has won a dominant position. Part of its attraction is the large collection of application programs its vendors supply. For example, the MathWorks Inc. (vendor of Matlab) offers "toolboxes," or collection programs, for specialized tasks; recent toolboxes include one for neural networks and symbolic math. Matlab also has the ability to call programs in Fortran or C. Other application programs are available at no charge on the Internet. A major upgrade to Matlab (Version 4.0) has lately been released for Microsoft Windows and other platforms, with a graphical user-interface, better graphics, and many other improvements.

The success of Matlab and other matrix-based general math programs has spurred the development of still more products of this genre. A new product, Xmath (for workstations), is gaining popularity. A new package from Harmonic Software, O-Matrix (for PCs running MS-DOS), resembles closely an earlier version of Matlab but costs less and does somewhat more.

A major product for exploratory math analysis is Mathcad, a user-friendly package with a graphical interface. Its vendor characterizes it as a "scratchpad" to emphasize its usefulness for informal calculations. Mathcad allows text, equations, and graphics to be included on the same page,

so that the documentation of a calculation is easy to follow. However, it is slower than the matrix-based programs mentioned above, and therefore less useful for number-crunching applications. Other math packages with graphical user-interfaces are available for the Macintosh, for example, HiQ (from Bimillennium).

An interesting development of late has been the incorporation of neural network technology into programs intended for general technical users. Running under Microsoft Windows, VisSim is a modeling/simulation program that has recently added learning capabilities, based on neural networks, for use in systems identification and for other purposes.

SOME NEW, SOME OLD. Improved user-friendliness has been a key factor driving the evolution of math software. Vendors are moving strongly toward incorporating graphical user-interfaces, but at the cost of becoming larger and running more slowly. Among others, Matlab and Xmath now boast software devices such as buttons and sliders to control important program parameters.

The shift to the graphical user-interface has had a beneficial effect on computer algebra programs. These complex programs compel users to adjust to many commands and parameters to guide their operation. In Macsyma, users can now enter lots of commands, at least in part, by a mouse from a menu.

User-friendliness, however, is still an issue with computer algebra programs. They probably never will be as easy to use as spreadsheets (although Derive comes quite close), but they clearly can be further improved [see "What the other half thinks," p. 59].

INTERACTIVE GAINS. A welcome development has been the rise of notebook-style interfaces, which allow a user to interweave text, graphics, and calculations in one interactive document. Mathcad, with its interactive "scratchpad" interface, is a particularly effective implementation of this concept. Other programs having interactive capability are Mathematica and Maple. Mathematica has long featured a notebook interface for many platforms (this summer its developers announced a version for Unix systems). Waterloo Maple has included a similar interface in the latest release of Maple for Microsoft Windows and other platforms.

The notebook-style interface does more than increase user-friendliness. As implemented in Mathematica and Maple, it sets up a two-way communication between the user and the program, with the kernel (the part that does the calculations) running in the background. The notebook enables a user to create an interactive document—a whole textbook, perhaps—that combines formulas, graphics, text, and (on some platforms) sound and animation.

For instance, a student can use a Mathematica or Maple notebook as a text, and study interactively such subjects as analog or digital filtering. This is an attractive feature for engineers, too, though some advanced users prefer the older command line interface in Maple and Mathematica because of its ease in running batch files for lengthy calculations.

Software packages are now appearing that combine the features of symbolic and number-crunching programs, or in other respects greatly extend the capabilities of the programs. Mathcad has had symbolic capabilities (a limited version of Maple) for several years. The Symbolic Math Toolbox for Matlab, which includes the Maple symbolic math package, is due out this fall. Wolfram Research has just announced programs to link Mathematica to the spreadsheet program Microsoft Excel and to the data acquisition program LabView (National Instruments Corp.), which smooths the job of entering masses of data from a spreadsheet or data acquisition board.

If successful, the coupling between a high-end symbolic math program and a fast number-crunching one could offer the best of both worlds. But these are quite different products, and developers might require some time to devise optimal marriages between them. The increase in functionality

may be offset by greater complexity.

Another welcome development has been the arrival of multimedia in math programs. Mathematica includes sound and animation capabilities in its versions for some platforms. Maple V Release 2 supports a multimedia interface for Unix under X-Windows. And Matlab, in its newest version, now offers animation and sound output.

Also important has been the increased use of the Internet in the distribution of information and files among users. Vendors of Maple, Mathematica, and Matlab, among others, maintain file transfer protocol (FTP) sites on the Internet from which users can download files free of charge.

Finally, software vendors are exploring novel publishing arrangements, looking at different ways of using math software in the classroom. Third-party guides to Matlab, Mathematica, Maple, and other such programs are sold in college bookstores, much like guides to spreadsheets. New engineering and science textbooks are coming out regularly that incorporate the use of these programs. So are inexpensive student versions (more limited than the full-priced editions) of many programs.

Some of these lower-cost programs have been very successful. An outstanding example is the student version of Matlab, introduced a year ago by Prentice Hall for both the Macintosh and MS-DOS personal computers. To date about 50 000 copies

Math software and the Internet

The Internet has developed into a formidable resource for users of math software (and many other engineers as well). Its most obvious benefit is electronic mail, which is used by a reported 15 million people. To exploit the resources of the Internet, the user generally needs some familiarity with the Unix operating system.

The network is in addition the meeting ground for many news groups specializing in topics of interest to engineers and scientists. Several news groups provide forums for spirited and often heated discussion about mathematics software. An active news group, sci.math.symbolic, has postings that range all the way from discussions about the finer points of symbolic computation to queries by novice users.

Often the software developers themselves post responses to users' questions or enter into discussions. One debate that sporadically erupts concerns the relative merits of Mathematica and Maple (participants in the debate clearly have strong feelings about the issue). The news group comp.soft-sys.matlab covers Matlab, and occasionally other numerical packages as well. The news group sci.math.num-analysis has ongoing discussions about numerical methods. Another news group of potential interest is sci.engr.control, which specializes in control theory and applications.

Access to great quantities of information is provided through the Internet's File Transfer Protocol (FTP) facility. Wolfram Research Inc. (Mathematica's developer) maintains a library called MathSource, which has a large collection of application programs and notebooks for Mathematica, including notebooks on filter design, circuit and wavelet analysis, signal processing, and much more.

The MathWorks Inc. (Matlab's vendor) has started a new FTP facility at ftp.mathworks.com that allows anyone interested in Matlab, whether or not a customer, to share files and obtain MathWorks product information.. Waterloo Maple Software Inc. maintains an FTP site at daisy.uwaterloo.ca.

Sites elsewhere around the world maintain collections of programs that users can download electronically. Many programs are shareware, which the user can obtain free of charge but is expected to pay for later by donating money to the developer. Other programs are free.

Additional resources include documents called FAQs (answers to frequently asked questions) for various subjects [see To probe further, p. 87].

Finally, there are several news lists on math, which, while automatically sending electronic mail to subscribers and providing a convenient forum for discussion, can often overwhelm a user with too much mail.

—K.R.F.

have been purchased and the program is reportedly the biggest seller in the engineering book market. Many vendors offer special prices or inexpensive site licenses to educational institutions.

Such determination to meet customers' needs is desirable. But even more could be done, as evidenced by customer feedback. Users often post complaints on the Internet about the unresponsiveness of some software vendors, including (inexplicably) the repeated failure of a large software company to notify users that upgrades to its product are available.

THOUGHTFUL CHOOSING. With such a wide range of math programs to choose from, engineers should weigh their requirements carefully before selecting one. A few guidelines may help in narrowing the choices.

For simple mathematical needs, which probably describe those of most engineers most of the time, any of several general-purpose math packages would be fine. Universities frequently adopt Mathcad or Matlab for student and research use. The former is simple to use and has a graphical notebook-style interface; the latter requires minor programming (a rusty skill among some engineering students) but is much faster for numerical calculations. Both programs are supplied with many engineering applications, but Matlab is more efficient at number crunching, making it a popular choice among electrical engineering departments and companies.

For symbolic math, the programs most often picked by universities are Maple and Mathematica, although Macsyma should be considered as well. These three bear a generic resemblance to each other, but differ in many respects. Mathematica has a larger variety of application software for electrical engineers, earning it the top slot in EE departments. Macsyma is the most comprehensive and arguably the most reliable computer algebra program. Developing programs for these packages requires a large commitment in time and effort, and users who expect to do a lot of programming should compare them with all due diligence. They all, however, may be used effectively in a simple interactive mode that does not require programming.

But other programs in the table should be explored as well. Derive is an effective computer algebra program for low-end PCs running Microsoft MS-DOS, including one palmtop computer, and is simpler to use than the larger symbolic math packages. The Theorist (Prescience Corp.) or HiQ (Bimillennium) are effective general-purpose math programs for the Macintosh. As for very large numerical problems, extensive signal-processing calculations, or extensive statistical calculations, specialized packages could provide efficient solutions. These include the collections of math routines from the Numerical Algorithms Group and Quantitative Technology Corp. or the signal-processing or statistics software listed in the table. ◆

What the other half thinks

During the preparation of this article, *IEEE Spectrum* requested viewpoints of math software users who are participants in the sci.math.symbolic news group on the Internet. Three responses follow.

William G. Dubuque, of the Massachusetts Institute of Technology, Cambridge, stated: "There is so much complexity underneath a computer algebra system that it is very difficult to convey to the unsophisticated user how to go about modeling his problem correctly. I think there is much more that can be done than what is currently available, however."

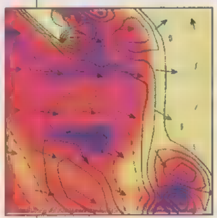
Jeffrey C. Kantor, of Notre Dame University in Indiana, wrote: "From my point of view as an educator, the development of textbook resources has done more for the adoption of the advanced math packages by a broad range of users than any other factor."

Malcolm Slaney, of Apple Computer Inc., Cupertino, CA, said: "I think the most exciting advance is the availability of the notebook paradigm to symbolic math programs. Mathematica has had one for a while. Now Maple is doing it. Hurray!"

ABOUT THE AUTHOR. Kenneth R. Foster (F) is associate professor in the department of bioengineering, University of Pennsylvania in Philadelphia. His e-mail address is kfoster@eniac.seas.upenn.edu.

Seeing data in action

New and improved packages are further popularizing powerful Windows-based visualization tools for engineering applications



Things have definitely changed for the better. Less than 15 years ago, engineering with the aid of computers meant Fortran programs keypunched onto 80-column cards or, for the lucky ones among us, timesharing by teletypewriter. Today, analyzing data means using a mouse to point and click at objects on the screen, and brilliant data analysis applications from software developers have revolutionized the way engineers solve their problems. There is now software for analysing complex electric or mechanical systems, filtering data, solving linear equations, evaluating integrals, analyzing simulations, designing experiments, and, in general, analyzing megabytes of data.

The use of graphics, in particular, can be literally an eye-opener when used to help the visualization of data. The opportunity to analyze data visually, rather than by looking at numbers, can sharpen and augment insight into mathematical and statistical analyses.

There is perhaps no more powerful tool for data analysis than the human eye. In alliance with the brain, the eye's ability to size up an object's shape, texture, dimensions, and movement often leads to understanding and comprehension. The transformation of a set of equations into a graph, or a table of numbers into a picture, speeds users' arrival at a grasp of their data and uncovers hidden patterns in it.

Ken Kornbluh
SciTech International

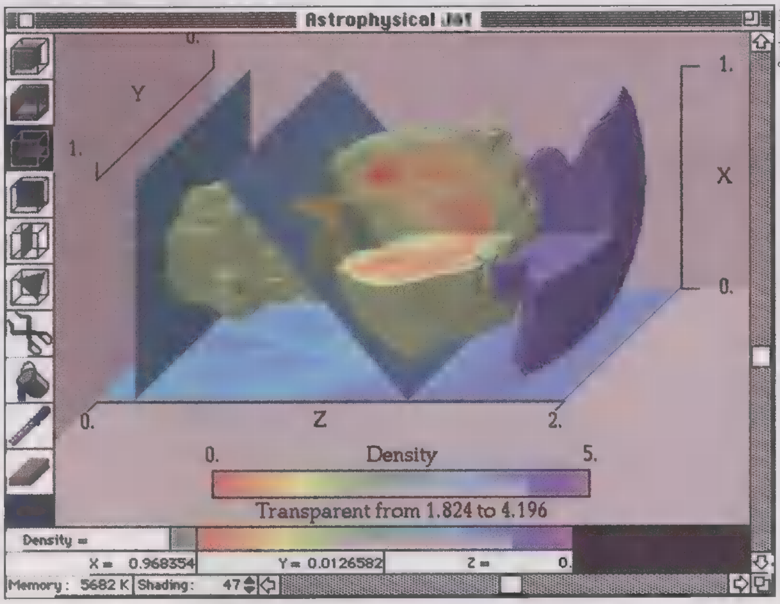
Data analysis software, it is widely held, is a mature industry, since the best minds in it have spent thousands of man-years developing tools. Not so, according to Richard Petti, president of Macsyma Inc., developer of a data analysis and mathematics tool. "The cost of computation, the output per unit of input, is changing by orders of magnitude at an incredible rate...this is an historic rate of change that happens very rarely," he has observed. "It is opening up a lot of new opportunities." New tools are more than ever using computer graphics to represent complex sets of numbers, and make sense out of data. More recently, data analysis software developers have concentrated on increasing the features of their programs having to do with visualization and exploratory data analysis, and on their product's ease of use.

Extensive use of color, three-dimensional rotating graphics, representation of equations symbolically or graphically, animation, sound, and more links between data and graphs are among the latest features in data analysis and visualization software. Spyglass Inc. is one company that has bet its future on visualization: its Dicer and Transform are the state of the art in graphic visualization. Dicer lets the user take 3-D data, such as the material spewing out of a galaxy into the intergalactic space, display it graphically, and then take a two-dimensional slice through it at any point to examine the data further [see photo].

But, at its best, visualization is more than turning numbers into charts. The other techniques it encompasses can help its user manipulate formulas and data to complete a job without delay, without fuss, and with the greatest level of insight. One of the best-known programs that illustrates the basics of visualization is Simulink, by The MathWorks Inc. Designed specifically for simulating complex systems, Simulink allows design engineers to create their models, and visualize their systems functions simply by moving control blocks with a mouse.

Engineers say that the Simulink's control blocks mimic the way data is analyzed and therefore is much easier to use than systems that use equations or models.

DADiSP, by DSP Development Corp., adopts another approach to visualization. It is a dynamic multiple-window worksheet, in which each window contains data, graphics, or analyses, which can be linked together. A change in the data in a window automatically ripples through all the other windows, updating them.



Spyglass Inc.

Slices through three-dimensional depiction of a jet of material spewing from a center of a galaxy out into intergalactic space were obtained by researchers at the National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign. They used Spyglass Inc.'s Dicer, a volumetric data analysis and presentation software package for the Macintosh.

EXPLORATORY ANALYSIS. The techniques of exploratory data analysis (EDA) have been around for some time but only now are entering the mainstream of statistics and data analysis in a big way. Classical inferential analysis begins with a hypothesis, which followed first by an experiment or model and then by statistical or mathematical analysis and testing. An example might be performing a regression and examining residuals and test results to check its goodness of fit. EDA, in contrast, makes short work of displaying data, identifying and tagging outliers and exceptions, and quickly re-doing the regression to see how well the new curve fits. EDA emphasizes data display: it finds simple functional descriptions of pat-

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terns in the data, and examines the residuals for evidence of deeper patterns or interesting exceptions. The idea behind EDA is that the tools should assist in the process of discovery, helping the engineer to develop a better understanding of the data first, and only then analyze them accurately.

Rotating 3-D plots, of the kind obtained with the Systat package from Systat Inc., let the user identify outliers and develop insights into the data. The best of these tools link plots and data so the user has only to click on a point to immediately see its coordinates or values, or use the mouse to select a subset of data for analysis. EDA was the start of a growing trend to equipping engineers to discover the patterns hiding in real data. Software developers in ever greater numbers are following pioneer Data Description Inc., developer of Data Desk 4 for the Macintosh, and are adding features for exploratory data analysis to their packages. For example, Systat Inc., developers of Systat; SLP SA in Paris, developers of STATlab; and Stat-Sci, developers of S-Plus, have added 3-D rotation, scatterplot matrices, animation, and more [see table].

EDA does more than display 3-D data and rotate them, it actually performs data analysis. PV-Wave by Visual Numerics, Houston, TX; Data Desk 4 by Data Description, and Systat by Systat Inc. enable users to store and play back animations of analyses. For example, Systat on the Macintosh utilizes Apple's QuickTime audiovisual software to create "movies": it links frames made as one or more variable

(Continued on p. 73)

Data analysis and visualization

Product and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Abacus Concepts Inc., Berkeley, CA; 510-540-1949; fax, 510-540-0260					
StatView $595 Circle No. 293	Mac (any)	System 6.0.5, 2 MB of disk space, 2 MB of RAM	Integrated data analysis, graphing, and presentation package	Extendable with statistical modules; ability to save suites of analyses as templates	Winner of 1992 MacUser Editors' Choice Award for best new science/engineering product; six-time winner of Macworld World Class Award for best statistics software
Amtec Engineering Inc., Bellevue, WA; 206-827-3304; fax, 206-827-3989					
Tecplot 6.0 IBM PC: $649 Unix: $1695 VMS: $1695 Circle No. 294	IBM PC/DOS; Unix workstations from HP, DEC, SGI, IBM, DG, Sun, VMS workstation from DEC	5 MB of disk space, 4 MB of RAM	Scientific data visualization package; combines X,Y plots, 2-, 3-D surface and 3-D volume plots; allows nonrectangular grids	3-D volumetric visualization features: iso-surfaces, 3-D particle trajectory, arbitrary slicing, display of selected grid surfaces	Allows input of multiple blocks of 2- or 3-D data; data may be plotted in curvilinear selected grids or finite elements
Aptech Systems Inc., Maple Valley, WA; 206-432-7855; fax, 206-432-7832					
Gauss Unix: $1995+ PC: $995 **Gauss Light** (entry-level version) Unix: $295; PC: $150 Circle No. 295	PC compatibles; Unix workstations: IBM RS/6000, HP 9000/700 & 800, Sun Sparc series, SGI, Solaris x86	[PC version] 386 or 486 with/FPU, 4 MB each of disk space and RAM; [Unix version] Call	Complete mathematical analysis package including 2- and 3-D Publication Quality Graphics, over 400 analysis functions, and a matrix-based programming language with debugger; provides a comprehensive environment for data manipulation, analysis, and visualization	New linear algebra functions, improved user interface, tools for building custom interactive analysis and visualization environments added to Unix version; updated optional application modules for simulation and more	Comprehensive analysis capabilities for many disciplines including engineering, physical sciences, biometrics, behavioral sciences, statistics, and econometrics
The Athena Group Inc., Gainesville, FL; 800-741-7440; 904-371-2567; fax, 904-373-5182					
Monarch Filter Digital Design, Siglab, Codegen: $99 **Adaptive:** $399 Circle No. 296	PC compatibles	MS-DOS 3.0 or later, 2 MB of disk space, 640 kB of RAM	Filter Design supports FIR and IIR digital filter design; includes Siglab—a mathematical signal and systems analysis tool, and Codegen—a programming tool that supports DSP microprocessors; also includes software that implements adaptive filters	Price reduction and modularization; Siglab for Windows option; additional DSP microprocessor support	Integrated design and testing environment supported by analysis and visualization tools
BBN Software Products, a division of Bolt Beranek & Newman Inc., Cambridge, MA; 617-873-5000; fax, 617-873-6153					
BBN/ Cornerstone $1795+ Circle No. 297	HP 9000/700 series, Sun Sparc series	[Unix] HP 9.0 or later; [Sun] OS 4.1.2 or later, 40 MB of disk space, 16 MB of RAM, digital audiotape media, 8-bit color monitor	Fully integrated set of intuitive data access, visualization, analysis, and presentation tools; graphics; on-line, context-sensitive help; workman diagram with automation capabilities	BBN/Cornerstone Extension Language (CEL) for object-oriented programming; rapid application development; integrated with BBN/Cornerstone and RS/Series software	Point-and-click data access; automate and capture analysis capabilities
RS/Series Software $595+ for RS/1; optional modules extra Circle No. 298	IBM DOS PCs and compatibles; DEC VAX/VMS, RISC/Ultrix; HP-UX; Sun Sparc series; IBM RS/6000	[IBM PC] 386 or later, 40 MB of disk space, at least 1 MB of base memory, at least 1 MB of RAM	RS/1: menu-driven data analysis and graphics package RS/QCA II: full range of SQC functions RS/Explore: statistical advisory application RS/Discover: menu-based environment for setting up and analyzing experiments and interpreting results	RS/Explore and RS/Discover Rel. 3.0 offer support for mixture and nested experiments, an on-line glossary, and greater ease of use	Integrated family of data analysis software; data access and data management; RPL programming language for customization; guidance and interpretation of results
Biosoft, Ferguson, MO; 314-524-8029; fax, 314-524-8129					
Fig. P for Windows $499 Circle No. 299	IBM PC 386 or better	Windows 3.1, 2 MB of disk space	General-science graphics package, including curve fitting of up to 60 parameters	Windows compatibility; unlimited data sets per graph; more on-screen editing	—
Fig. P (DOS and Windows) $499 Circle No. 302	IBM PC	[DOS] DOS 3 or later, 640 kB of RAM, 2 MB of disk space [Windows] 3.1 or later	Presentation graphics and curve-fitting package	Windows version	Equation plotter with numerous plot types; large spreadsheet editor; comprehensive yet easy to use

Data analysis and visualization *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
BMDP Statistical Software Inc., Los Angeles, CA; 800-238-2637, 310-479-7799; fax, 310-312-0161					
BMDP/Diamond 1.0 Unix version: $695 OS/2 version: $695 Circle No. 303	IBM RS/6000 Sun, IBM PC running OS/2	[IBM PC] OS/2 V.2.0 or later, 2 MB of disk space, 4 MB of RAM (8 MB recommended), color monitor; [Unix] IBM RS/6000, (AIX), Sun (OS 4), X-Windows, 2 MB of disk space, 8 MB of RAM, color monitor	Data exploration and visualization: provides many multidimensional views of data; working with color, the user can quickly explore relationships between variables in the data set	New product	Highly interactive environment with dynamic linkage among all open windows, including graphics, summary statistics, and raw data; easily transforms, sorts, and subsets data; includes 9-dimensional visualization tool, Ice
BMDP Release 7.0 $995+ Circle No. 304	IBM PC, VAX, DECstations, Sun, IBM RS/6000, HP, SGI, MIPS, IBM and other mainframes	[IBM PC] DOS 3.3 or later, 18 MB of disk space, 640 kB of RAM; [IBM PC, extended memory version]: DOS 3.3 or later, 386 DX or 486 or better, math coprocessor, 25 MB of disk space; [Other platforms] varies	Comprehensive statistical software package, including Anova, regression, multivariate statistics, time series, survival analysis, and more	Data import/export, including SAS and SPSS files; mentor, intelligent command language generator; improved graphics	Well-known, reliable software package for sophisticated statistical applications and research
Comdisco Systems, a business unit of Cadence Design Systems Inc., Foster City, CA; 415-574-5800; fax, 415-358-3601					
Signal Processing WorkSystem (SPW) $25 000+ Circle No. 305	Sun Sparc series, HP 9000/400, 700, DEC	[Sun] OS, Openwindows 3.0 or X11R4/Motif, 120 MB of disk space, 24 MB of RAM; [HP9000/400] SR 10.4, X11R4/Motif, 92 MB of disk space, 40 MB of RAM; [HP9000/700] HP-UX 8.07, HP VUE, 170 MB of disk space, 32 MB of RAM; [DEC] Ultrix 4.3, DECWindows/Motif, 160 MB of disk space, 32 MB of RAM	Industry-standard tool for rapid simulation, virtual prototyping and implementation of communications, DSP, general digital systems; system-level methodology, graphical design entry, signal/data flow simulation paradigm	Wireless communications library, virtual product prototyping library, multirate system design capture	Automatic C and VHDL code generation from graphical design description; tight links to industry-standard VHDL simulation and synthesis tools
Data Description Inc., Ithaca, NY; 607-257-1000; fax, 607-257-4146					
Data Desk 4.1 $595 (Educational discounts) Circle No. 306	Mac	System 6.08 and greater, 1 MB of disk space, 1 MB of RAM	Interactive and graphical statistics package combining exploratory data analysis tools with traditional statistics procedures	Eliminated 32 000 case limit; added many statistical features and visualization tools	Still the fastest statistics package on the Macintosh
Dataq Instruments Inc., Akron, OH; 800-553-9006; fax, 216-666-5434					
WinDaq/200 $595 Circle No. 307	IBM PC or compatible	DOS 5 and Windows 3.1	Multi-tasking data acquisition software providing real-time display and disk-streaming to 80 000 samples per second	Multi-tasking attributes	16-channel support, simultaneous acquisition and analysis
WinDaq/EX $595–$795 Circle No. 308	As above	As above	Time, statistical, and frequency-based waveform analysis	Data file import and export facilities allowing compatibility with a wide range of software packages	Disk-streaming, multi-tasking design allows simultaneous data acquisition using WinDaq/200
Digital Optics Ltd., Auckland, New Zealand; (64+9) 478 5779; fax, (64+9) 479 4750					
V for Windows US $1995 Circle No. 309	IBM PC 386 or better	Microsoft Windows 3.1, 3 MB of disk space, math coprocessor recommended	Advanced image enhancement and analysis package with support for >16-bit images	Windows version; 32-bit processing, even in Windows 3.1; built-in programming language	Used in diverse applications in eight countries
DSP Development Corp., Cambridge, MA; 617-577-1133; fax, 617-577-8211					
DADiSP for DOS and Windows IBM PC: $995+ Workstations: $4495 Circle No. 310	IBM PC: 386 or better; DECstations; DECAlpha; HP: 400 Apollo; 9000/300, 400, 700, 800; IBM RS/6000; NeXT; SGI; Sun: Sparc, Solaris; VAXstations	[IBM PC and clones] MS-DOS 3.0 or later	Data analysis and visualization tool	Support for Microsoft Windows; advanced statistics	Engineering math and statistics, signal processing, data editing and reduction, matrix manipulation, and hardcopy printing and plotting
DADiSP/Filters IBM PC: $695 Circle No. 311	As above	As above	Design, display, and analysis of FIR and IIR digital filters	No programming required	Integrated with DADiSP
DADiSP/STATS IBM PC: $495 Workstations: $795 Circle No. 312	As above	As above	Performs set of statistical tests; presents information graphically using menu-driven module	As above	Used as an add-on module to DADiSP
DADiSP/LT 2.0 IBM PC: $495 Circle No. 313	As above	MS-DOS 3.0 or later, 2 MB of RAM	Menu-driven module allows user to collect data from A/D board	As above	Integrated with DADiSP
GPIBLab IBM PC: $495 Circle No. 314	See DADiSP for DOS and Windows	MS-DOS 3.0 or later	Allows instrument setup, controls and transfers data from IEEE-488 based instruments	No programming required	Integrated with DADiSP

Package [redacted] price	Platform	Requirements	Brief product description	Recent enhancements	[redacted] and features
Dynetics Inc., Huntsville, AL; 800-922-9261, 205-922-9230					
DataFlo $4800 Circle No. 315	All Unix platforms	Color monitor, 10 MB of disk space, 16 MB of RAM	A graphical programming environment for digital signal and image processing; the user can create and execute applications with [redacted] complete set of visualization tools	Motif graphical interface and enhanced primitive libraries	Lets user run applications on distributed multiprocessors; support for embedded processors available
Eighteen Eight Laboratories, Boulder City, NV; 800-888-1119; fax, 702-294-2611					
PL 2500 IBM PC: $2495–$5995 Circle No. 316	IBM PC	MS-DOS 3.0 or later, Windows 3.0 or later	Library for use in C, Fortran, or Pascal programs; hardware accelerator included	Interface to data acquisition cards	Handles large arrays of real floating-point numbers or complex integers; compatible with ISA bus
Future Graph Inc., Southampton, PA; 800-532-7634, 215-396-0720; fax, 215-396-0724					
f(g) Scholar $299 Circle No. 317	MS-DOS, Windows, OS/2	Graphics card (EGA or better), 7 MB of disk space	Data analysis package combining over 500 mathematical functions, a graphical spreadsheet, scientific and graphing calculator, a drawing package, and [redacted] programming language for building graphical scientific applications	Automatic curve fitting and graphing of data; math toolbars (Quick Buttons) that provide the user with instant access to hundreds of mathematical functions and analysis tools	Completely graphical; uses menus, toolbars, dialog boxes, and a mouse; functions include statistics, curve fitting, signal processing, calculus, linear algebra, transcendental functions, and more
Harmonic Software Inc., Seattle, WA; 206-367-8742; fax, 206-367-1067					
O-Matrix $95 Circle No. 318	IBM PC 286 or greater	MS-DOS 3.3 or later, CGA, EGA, VGA (SVGA) adapter, 3 MB of disk space, 1 MB of RAM	Matrix-based interpreted language with built-in linear algebra functions, graphics, and debugger	New product	Useful in all numerical analysis; structured programming
HEM Data Corp., Southfield, MI; 313-559-5607; fax, 313-559-8008					
Snap-Master Frequency Analysis $495 Circle No. 319	IBM PC/AT or better	MS-DOS 3.1 or later; Windows 3.0 or later; windows compatible display, coprocessor, and mouse recommended; 4 MB of RAM	Frequency domain calculations: FFT, auto/cross power spectrum, transfer function, coherence, impedence, forward/inverse FFT	DDE support; enhanced graphical interface; calculates up to 16 384 points per window	Quantify data using cursors on multiple waveforms; displays point values in tabular format; 13 window types available
Snap-Master General Analysis $495 Circle No. 320	As above	As above	Time domain analysis for analyzing data during testing or [redacted] post-process; arithmetic, trigonometric, logarithmic, statistical, correlation, differentiation, integration	DDE support; decision-making (IF...THEN...ELSE) capability; digital filtering	Plotting capabilities with cursors, zooming, panning, and histograms; define and store equations with point-and-click interface

Data analysis and visualization *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Hyperception Inc., Dallas, TX; 214-343-8525; fax, 214-343-2457					
Hypersignal for Windows Clearview IBM PC: $595 Circle No. 321	IBM PC: 386 or better	MS-DOS 3.1 or later, Windows 3.1, 4 MB of disk space, 4 MB of RAM	Graphical analysis and library of DSP processing functions for time and frequency domain files	Compatibility with Windows WAV files from 16-bit audio cards; more frequency graph types	Allows user to size, color, and arrange any number of time or frequency domain plots; menu-driven
Jandel Scientific, San Rafael, CA; 800-874-1888; 415-453-6700; fax, 415-453-7769					
SigmaScan/Image $495 Circle No. 322	IBM PC 386 or better	Windows 3.1, 256-color VGA, Microsoft-compatible mouse, math coprocessor recommended, 3 MB of disk space, 4 MB of RAM	Collects morphometric and intensity data from images displayed on PC monitor	New product	User traces objects or clicks on endpoints to make measurements from images; built-in SigmaPlot/Windows-compatible worksheet, annotation tools, plotting
SigmaPlot DOS/Windows: $495 Mac: $295 Circle No. 323	IBM PC 286 or better (DOS), 386 or better (Windows), Mac Plus or better	MS-DOS 3.0 or later, graphics card, 5 MB of disk space, 535 kB of conventional memory; Windows 3.1, 5 MB of disk space, 4 MB of RAM; [Mac] System 4.2 or later, 5 MB of disk space, 2 MB of RAM	Scientific graphing software for publication-quality graphics	Windows version; multiple pages and worksheets; cutting and pasting between applications	Includes error bars, axis breaks, multiple axes, nonlinear curve fitting, mathematical transforms, regressions, and more
SigmaStat DOS: $395 Circle No. 324	IBM PC 286 or better	MS-DOS 3.0 or later, 3 MB of disk space, 535 kB of RAM	Statistical software for scientists and engineers	Advisor; assumption checking; missing data handling	Assists user in selecting tests for data, checks assumptions, and includes explanation of results with reports
Table Curve 3D for Windows $495 Circle No. 325	IBM PC 386 or better	Windows 3.1 or later, Microsoft-compatible mouse, math coprocessor; graphics coprocessor; 256-color VGA recommended; 2.5 MB of disk space, 4 MB of RAM	Surface-fitting package; fits equations to user-supplied *x-y-z* data sets with graphic display of surface fits	New product	Extensive and automated surface-fitting capabilities; similar interface to TableCurve for Windows (2-D version)
TableCurve for Windows $495 Circle No. 326	IBM PC 286 or better	MS-DOS 3.3 or greater, Windows 3.1 with 256-color graphics card, 80X87 math coprocessor (highly recommended), mouse, 2.5 MB of disk space, 4 MB of RAM	Curve-fitting package automatically fits equations to user-supplied *x-y* data sets	Windows version; simultaneously view curve fits, residuals, plots, data and numeric summaries, and ranked equations list	Includes nonlinear equations; user-defined functions; data smoothing with FFTs; Savitsky-Golay, polynomial interpolation, and Lowess
TableCurve for DOS $495 Circle No. 327	IBM PC 286 or better	MS-DOS 3.0 or later, 1.3 MB of disk space, 640 kB of RAM	Curve-fitting package ranks equations to *x, y, z* set with graphic display of fits	None	User-defined functions; FFT smoothing; ranking criteria offer enhanced fitting capabilities
Keithley Instruments Inc., Taunton, MA; 508-348-0033; fax, 508-880-0179					
Asyst 4.0 $1995 Circle No. 328	IBM PC XT/AT 386/486	MS-DOS 3.0 or later, math coprocessor, 5 MB of disk space, 1 MB of RAM	Programming language designed for data acquisition, data analysis, and graphics	Supports larger programs and data sets; added counter-time support; added new analysis/filter functions	Additional options on copy protection and run-time system development now available
Viewdac 2.1 $1995 Circle No. 329	IBM PC 386/486	MS-DOS 3.0 or later, math coprocessor, EGA or better, 15 MB of disk space, 6 MB of RAM	Windows-oriented package with integrated data acquisition, analysis, and graphics enables complex data acquisition applications without the need for programming	Speeded up sequence execution; added analysis functions; added improved GPIB support	Supports preemptive multitasking and interactive post-acquisition analysis
Macallan Consulting, Milpitas, CA; 408-262-3575; fax, 408-262-3575					
Nodal 2.0 $395 Circle No. 330	IBM PC, Mac, Sun, HP, DEC, NeXT	Mathematica	Circuit analysis and design, symbolic and numerical analysis; voltage/current and s-parameters; transmission line design utilities	Completely recoded in functional style; component design functions added in version 2.0	Noise analysis; object-oriented CAD maximizes ease of use and flexibility
The MathWorks Inc., Natick, MA; 508-653-1415; fax, 508-653-6284					
Matlab Image Processing Toolbox PC and Mac, single-user: $695+ (Educational discounts) Circle No. 331	IBM PC 386/486/Pentium and compatibles, DEC, HP, IBM, Mac, SGI, Sun workstations and servers	20 MB of disk space, 16 MB of RAM (most workstations) [illegible] MB of both disk space and RAM (DECstation)	Extendable system for image and 2-D signal processing; 2-D filter design, image filtering and restoration, image enhancement and analysis, 2-D transforms; color, geometric, morphological operations; customizable toolbox	New product	Fully integrated with Matlab and other toolboxes
Matlab Signal Processing Toolbox PC and Mac: $495+ (Educational discounts) Circle No. 332	As above	As above	Environment for signal analysis, filter design and filtering, spectral analysis, parametric modeling and visualization of time-series data	Handles linear phase filters and multirate signal processing; has new graphics for visualizing data and system behavior, modulation, and related functions	Integrated with related Matlab toolboxes as well as Simulink dynamic system simulation software

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Data analysis and visualization *(continued)*

Product and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
The MathWorks Inc., Natick, MA; 508-653-1415; fax, 508-653-6284					
Matlab Statistic Toolbox PC and Mac single-user: $695+ (Educational discounts) Circle No. 333	As above	As above	Matlab functions for data analysis and interactive graphics; descriptive statistics, probability modeling; regression and random number generation; GUI-based tools let user interact directly with plots	Descriptive and inferential statistics; interactive graphics for visualization of functions, data, and probability distributions; random number generators	All functions are Matlab M-files; provides access to source code so users can modify and combine algorithms
MicroCal Software Inc., Northampton, MA; 413-586-2013; fax, 413-585-0126					
Origin $495 in U.S. $600 elsewhere Circle No. 334	IBM PC 286, 386, 486, or compatible	Windows 3.0 or later, 2 MB of disk space, 2 MB of RAM	Graphics and data analysis in Windows: open-ended architecture supports add-on modules; built-in scripting language and publication-quality graphics	3-D/contour module; OLE support; user interface module, data acquisition module	Multilayered plot format; performs data analysis such as FFT and curve fitting
Mihalisin Associates Inc., Ambler, PA; 215-646-3814; fax, 215-643-4896					
Temple MVV IBM PC, Mac: $5000 SGI, Sun: $10 000 Circle No. 335	IBM PC 386 or better, Mac IIsi or better, any SGI, Sun (any Sparc)	[IBM PC] Windows 3.1 or later; [Mac] System 7; [SGI] any system; [Sun] Sparc Solaris 1 or 2	Multivariate visualization package allows user to visualize records in up to 10 dimensions (independent variables); based on U.S. Patent No. 5228119	Contouring; enhanced database management tools, annotation features; visualization templates	Performance enhancements in excess of four orders of magnitude
TempleGraph $1290 Circle No. 336	Sun (Sparc), any SGI	[Sun] Sparc Solaris 1 or 2; [SGI] any system	Integrated data analysis and publication-quality graphics package; support *x,y* and *x,y,z* data with interactivity	Added support for *x,y,z* data and random access graphical user interface provided	Slider widgets let user control embedded parameters; provides graphical feedback on data plot
Momentum Data Systems, Costa Mesa, CA; 714-557-6884; fax, 714-557-6969					
QEDesign PC: $495, $895 (QEDesign 500, 1000), Mac: $995 Sun4: $4200 single floating license Circle No. 337	PC, Mac, Sun4	[PC] Windows 3.0 or later, DOS 3.1 or later, Macintosh Version 6.0 or later; [PC and Mac] 2 MB of disk space; [Sun4] Sun O/S 4.1 or later, 7 MB of disk space	Digital filter design and analysis system does IIR and FIR designs with both S- and Z-domain analyses	Visual design methods, signal-to-noise ratio calculations, enhanced graphics	New window design capabilities
DSPworks PC: $495, Mac: $495, Sun4: $2000 Circle No. 338	PC (Windows), Mac, Sun4	As above, minus DOS details	Data acquisition and signal manipulation system; supports over 25 DSP boards with many math and signal-processing functions; real-time displays include oscilloscope and spectral displays include classic waterfall	Graphical editing capabilities, additional board support, LPC speech analysis	Supports continuous real-time data acquisition to disk at high data rates
National Instruments, Austin, TX; 512-794-0100; fax, 512-794-8411					
LabVIEW IBM PC and Mac: $1995 Sun: $3995 Circle No. 339	IBM PC/Windows, Mac, Sun Sparc series	[IBM PC] 386/25, Windows, 387 coprocessor, 16 MB of disk space, [illegible] MB of RAM; [Mac] any, 4 MB of memory; [Sun] Sparcstation 1, 12 MB of disk space, 24 MB of main memory, 32 MB of disk swap space	Analysis library with functions for array and matrix manipulation, complex arithmetic, statistics, FFTs, curve fitting, digital filters, real and complex vector and scalar operations	Portability between all three platforms; measurement-based VIs can assume real-world time-domain signal input directly to data acquisition VIs; new 3-D graph and chart functions	Customizable data displays and presentation; GUI environment
LabWindows Full development system: $1495 Circle No. 340	IBM PC, DOS-based	IBM PC/AT, EISA, PS/2 or compatible with 286 coprocessor, numeric coprocessor recommended; EGA, VGA, Super VGA or Hercules adapter; 10 MB of disk space, ≥ 2 MB of RAM, 4 MB recommended	Set of software tools and libraries for developing programs in C and Basic for data analysis, instrument control, data acquisition, and presentation	CodeBuilder user interface for automatically designing and building programs; graph and cursor controls	Customizable data displays and presentation; ability to add custom functions to libraries
LabWindows/ CVI IBM PC: $1995 Sun: $3995 Circle No. 341	IBM PC/Windows, Sun Sparc series	[IBM PC: 386/33] MS-DOS 5.0, Windows 3.1 or later, 387 coprocessor, 20 MB of disk space, 8 MB of RAM; [Sun] 44 MB of disk space, 24 MB of RAM	Used to design portable instrumentation applications with C that run under Windows and Solaris	Portability between both platforms; automatic code-generation package; built-in libraries for data acquisition, analysis, and presentation	GUI for data visualization, building and customizing data displays and presentations; customizable functions
Operation Technology Inc., Irvine, CA; in the U.S.: 800-477-ETAP; elsewhere: 714-476-8117; fax, 714-476-8814, worldwide					
ETAP (Electrical Transient Analyzer Program) $650–$14 900 Circle No. 342	IBM PC compatibles	MS-DOS 3.3 or later, math coprocessor, parallel printer port, EGA color monitor or higher, 20 MB of disk space, 640 kB of RAM	Integrated package of programs with design, analysis, and operation of power systems capabilities; analyzes industrial and utility power system problems	Addition of harmonic analysis program; transformer load tap changers; transformer sizing for unit generators	Option menus; data editors with window frames; function key commands; on-line help; one full year software and engineering support, maintenance, upgrades

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Poly Software International, Salt Lake City, UT; 801-485-0466; fax, 801-485-0480					
PSI-PLOT 2.1 $299 Circle No. 343	Any IBM PC or compatible	MS-DOS 3.0 or later, 3 MB of disk space, 640 kB of RAM	Scientific graph; data processing; curve fitting; statistics	Batch processing; automatic legend; more plotting types; handles more data	GUI; 2- and 3-D graphics
Preston Scientific, Anaheim, CA; 714-632-3700; fax, 714-632-7355					
Slignalys Base package: $1500 plus options Circle No. 344	IBM PC 286 or better	IBM MS-DOS	Data acquisition; signal display; menu driven	C-compiler; user-interface tool kit; expanded FFT capability	Analysis and signal display options
Prowave Engineering Inc., Hsinchu, Taiwan; (886+35) 339650; fax, (886+35) 326709					
Signal Doctor US $5000 Circle No. 345	IBM PC 386/486 or compatibles	MS DOS 3.3 or later, one 8-bit slot	Two-channel spectrum analyzer; includes an on-line digital filter, orbit, octave, waterfall, and source generator, a dedicated modal testing and vibration diagnostic package, and an optional in-field rotor balancing system	On-line digital filter design, Windows version	Direct SMS Star model data interface; technical on-line help can be designed with a language other than English; can be used with ■ notebook PC and an extension box
Quantitative Technology Corp., Beaverton, OR; 503-626-3081; fax, 503-641-6012					
Math Advantage Prices vary with version Circle No. 346	Supercomputers, workstations, array processors, mainframes	Call	Signal, image, and seismic processing; simulations and scientific applications within ■ floating-point routine	Over 800 routines added	Available in C, Fortran, and Ada
Research Systems■ Inc., Boulder, CO; 303-786-9900; fax, 303-786-9909					
IDL IBM and Mac: $1500 Workstations: $3000–$15 000 Circle No. 347	Convex; DEC Alpha/OMS, VMS; RISC Ultrix; HP 9000; IBM RS/6000, PC/Windows; Mac, SGI, Sun	[IBM PC] Windows 3.1 or later, 256-color graphics card, 8 MB of RAM	Integrated environment for developing custom applications; mathematical analysis and graphical display capabilities	—	—

Data analysis and visualization *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Scientific Engineering & Tools, Reading, PA; 215-678-4991; fax, 215-374-9252					
ESPro(DOS) $895 Circle No. 348	386 or better	DOS 3.3 or better, 512 kB of disk space	Custom data analysis and visualization development systems	Unix customizable GUI, C code generator for application performance optimization and integration	General numerical analysis, complete ASCII I/O, precision graphical capability on most devices (CGI/GSS Unix ports provided)
ESPro(Unix) $2495 Circle No. 349	Sun, Unix 386/486	Solaris 2.1 or better, Unix System V	As above	As above	As above
Scientific Programming Enterprise, Haslett, MI; 517-339-9859; fax, 517-339-4376					
Plotit 3.0 for Windows $495 (Educ. and gov't. discounts) $395 Circle No. 350	IBM 386 or better	MS-DOS 5.0 and Windows 3.1, 6 MB of disk space, 2 MB of RAM	Industrial strength 2- and 3-D graphics and extensive statistics software for Windows, NT, and Chicago O/S	Added support for 32-bit NT and Windows 4.0, increased statistical tests and added extensive functionality	Extremely easy to use; DDE, DLL, OLE support; reads XLS files; seamless windows integration via OLE
SLP SA, Paris, France; in the U.S.: 800-622-3345; fax, 312-472-0472; in France: (33+1) 45 21 95 95; fax, (33+1) 45 21 90 29					
STATlab 7500 FF **GEOlab** 2500 FF Circle No. 351	IBM PC MS-Windows	2 MB of disk space, 4 MB of RAM	Package for exploring and analyzing data graphically; includes brushing tools, zoom, hypertext help, data dictionary; descriptive statistics, regression, correlation, contingency tables, tests, principal components, correspondence, factor and discriminant analysis	U.S. English version; factor analysis, multiple regression, image processing	Designed to work with huge data files; native windows application; data and graphics are linked; more than 60 graph types
Signal Analytics Corp., Vienna, VA; 703-281-3277; fax, 703-281-2509					
IPLab Spectrum 2.4 $1200 Circle No. 352	Mac II family, Centris, Quadra, with floating-point processor	[Mac] System 6.0.5 or later, 8-bit display, floating-point processor, 4 MB of RAM	Multipurpose image-processing program for visualization, enhancement, analysis, processing, data acquisition, and lab hardware control	Supports core Apple events; mosaic command allows user to join images; measurements and scripting expanded	Retains integrity of data values; free technical support; frequent updates from suggestions made by users; price includes one year of update
Prism 3.2 $5500 Circle No. 353	As above	As above, except for 8 MB of RAM	Provides array of advanced morphometric and statistical analysis features for image analysis and enhancement	—	Statistical analysis and plotting; allows user to add "scripts" to perform own routines
Signalogic Inc., Dallas, TX; 214-343-0069; fax, 214-343-0163					
DSPower $795+ Circle No. 354	IBM 80386 or better or Windows NT–supported platform	MS-DOS 5.0 or later, DOS/Windows 3.1 or Windows NT	Data acquisition and analysis package featuring a block diagram user interface	Full compatibility with Hypersignal-Macro displays and instruments; Matlab source code generation; additional support for new types of PC-based DSP/analog and multimedia hardware	Block diagrams are saved as source code; simulation and interactive analysis are seamlessly integrated; straightforward addition of user-defined blocks
Signal Technology Inc., Santa Barbara, CA; 805-899-8300; fax, 805-899-4344					
N!Power Family, DSP!Power Developer: $5000+ permanent license (lease $2500+) DSP!Power: $2000+ Circle No. 355	Sun Sparc series, HP 9000/7xx, DECstation, VAXstation, X Window server	15 MB of disk space, 16 MB of RAM, X Window device, OpenWindow, HPVue or Motif X toolkit, PostScript, EPS, CGM, HPGL or PICT hardcopy	Customizable point solutions and application framework for interactive graphics, analysis, DSP, data flow modeling and simulation	Wavelets; Wigner Ville; segmentation tools; transient detection; image and matrix processing; universal data input; 75 new commands/features	Object-oriented algorithms and graphics; interactive graphics in runtime mode; interchangeable interfaces; point-and-click customizing; OEM pricing
The Software Hill, Mountain View, CA; 415-969-4233; fax, 415-968-8563					
RPower 2.1 $345 Circle No. 356	IBM PC	MS-DOS 3.1 or later, 3 MB of disk space, 640 kB of RAM	Numerous statistical computations from regression, curve-fits to Anova; 3-D graphics, FFT, filter design, matrix operations	Added 3-D graphics; added numerous math engineering functions	—
Spiral Software, Brookline, MA; 800-833-1511; fax, 617-739-4836					
Easy Plot IBM MS-DOS: $349 Windows: $399 Circle No. 357	IBM PC or compatible	[MS-DOS] 350 kB of disk space, 640 kB of RAM; [Windows] Windows 3.1, 500 kB of disk space, 2 MB of RAM	Plotting and data analysis package; generates plots from user data, including spreadsheets; MS-DOS and Windows versions fully compatible	Both versions—500-kB file size; clipboard plotting minimizes use of data table	Allows user to plot directly from Excel, Lotus, Quattro files, source code available
Speakeasy Computing Corp., Chicago, IL.; 312-427-2400; fax, 312-427-4777					
Speakeasy IBM PC: $995 Other versions: contact vendor Circle No. 358	IBM PC, RS/6000, Sun, DEC, IBM MVS, CMS	MS-DOS 5.0 or later, 8 MB of disk space, 5 MB of RAM	A matrix programming language with graphics, on-line documentation, application development tools, and proven algorithms	New menu interface, hypertext, help facilities, spreadsheet data editor	Array and matrix algebra, econometric modeling, time series analysis, linear and quadratic programming, and differential equation solvers capabilities

Data analysis and visualization *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Spyglass Inc., Savoy, IL; 217-355-6000; fax, 217-355-8925					
Spyglass Transform Mac: $595 Unix: $995 Circle No. 359	Mac, 68020 or better; DEC: RISC workstation; IBM RS/6000 workstation; HP 9000 700/800; SGI:Sun SparcStation	[Mac] System 6.07 or later, System 7 for AppleEvent scripting and MathLink support; [Sun] OS 4.1 and above, Motif or Open Windows 3; [SGI] Irix 4.0 and later; [DEC RISC] Ultrix 4.2 and later; [HP] HP-UX 8.07 and later; [IBM] AIX 3.2 and later; Mac requires 4 MB of disk space; the rest require 8-bit displays and 16 MB of RAM	Visual data analysis package for 2-D data and images; create images; line graphs; contour, surface, or vector plots; overlays	Annotation of all plot types with titles, axis labels, numerical scales, tick marks; add back drops and skirts to surface plots; exchange data and commands between Mathematica and Transform using MathLink; macro capabilities; may exchange data with Dicer 2.0, Spyglass's volumetric (3-D) data analysis and presentation program, to create 3-D presentations and vice versa	Data import facility allows user to import virtually any data type; no programming is required; interpolate data using Kriging
Statistical Sciences (StatSci), a division of MathSoft Inc., Seattle, WA; 800-569-0123; 206-283-8802; fax, 206-283-8691					
S-PLUS 3.1 Windows: $1200 standalone Unix: $2800 (Multicopy, academic, and nonprofit discounts) Circle No. 360	IBM PC or compatible: 386 or better with math coprocessor; DECstation, HP 9000 300/400/700; IBM RS/6000, SGI: Iris; Sun Sparc	[IBM PC] Microsoft Windows 3.1 or later, 20–25 MB of disk space, [illegible] MB of RAM; [All others] 45 MB of disk space, 12 MB of RAM	Interactive computing environment with graphical data analysis system and object-oriented language; used for exploratory data analysis, graphics, statistics and mathematical computing	Enhanced speed; better memory utilization; new functions for computation and statistics; enhanced modeling capabilities	Used as an application package or a development environment for custom data analysis and graphics
Survo Systems Ltd., Helsinki, Finland; (35+8) 56 68 145; fax, (35+8) 56 68 146					
Survo 84C 5500 FIM (Academic discounts) Circle No. 361	IBM PC 386 or better	MS-DOS 3.2 or later, 12 MB of disk space, 640 kB of RAM	Interactive, integrated environment for statistical analysis and related areas including text processing, spreadsheet computing, matrix algebra, graphics, desktop publishing	Enhanced macro language; several new methods of statistical analysis; improved documentation	Editorial interface in job control; book on system including diskettes of a reduced freeware version available ($50 plus postage)
Systat Inc., Evanston, IL; 708-864-5670; fax, 708-492-3567					
Fastat 2.0 for DOS, Fastat 2.0 for Macintosh $495 each Circle No. 362	IBM PC: 286 or better Mac: 2 SE or better	[IBM PC] MS-DOS 3.0 or later, hard disk, 640 kB of RAM; [Mac] System 6.0.2 or later, hard disk drive, 2 MB of RAM	Midrange version of Systat statistics and graphics software; contains many of Systat's statistics and graphics functions	—	Software accompanied by one-volume set of documentation; free, unlimited technical support available; academic and volume discounts available
Systat 5.02 for Windows, Systat 5.03 for DOS, Systat 5.2 for Macintosh All versions: $895 Circle No. 363	As above	[IBM PC] MS-DOS 3.0 or later, 7.5 MB of disk space, 640 kB of RAM; Windows 3.1, 8 MB of disk space, 2 MB of RAM (4 MB recommended); [Mac] System 6.0.2 or later, hard disk, 2 MB of RAM	Statistics and graphics software; statistics ranging from basic to complex; complete set of graph types	General linear model functionality added to Macintosh version	Software accompanied by four-volume documentation set; free, unlimited technical support available; academic and volume discounts available
Techni-Soft, Livermore, CA; 510-443-7213; fax, 510-743-1145					
SIGX 3.0 (10/90) Workstations: $5000–$6250 (University discounts) Circle No. 364	Sun, SGI, HP 9000, IBM RS/6000, DECstations, VAX	Unix, HP-UX, AIX, Solaris, VMS, Fortran 77, X Windows, 5 MB of disk space	Performs DSP operations on signals; multichannel signals, images and matrices with over 200 DSP-type commands including basic, parametric, and adaptive signal processing	New pull-down menu system with enhanced graphics; new color map manipulation capability and enhanced signal-processing algorithms	Customizable DSP environment, including a tutor and optional SIG tools environment for code development
3-D Visions, Torrance, CA; 800-729-4723; 310-325-1339; fax, 310-325-1505					
Stanford Graphics 2.1 $495 Circle No. 365	IBM PC 386 or better	Windows 3.1 or NT, 12 MB of disk space, 4 MB of RAM	Power graphing and data	Greek and math true type on rotated axes; context-sensitive "right-click" menus; 86% speed increase	167 graph types, 2- and 3-D; curve-fitting, interpolation, FFTs and Fourier transforms; 3-D surface plotting and contouring options; 4-D 70-trillion-cell spreadsheet
TriMetrix Inc., Seattle, WA; 800-548-5653; 206-527-1801; fax, 206-522-9159					
Axum 3.0 $495 Circle No. 366	IBM PC/AT, 286, 386, 486, PS/2 and compatibles	MS-DOS 3.0 or later, computer graphics card and monitor, math coprocessor recommended	Technical graphics and data analysis package for PCs; allows user to create publication-quality 2- and 3-D graphs from data sets; performs advanced data analysis, data transformations, and curve-fitting	Nonlinear curve fitting; mouse support; new plot types: color-filled contours, area charts, automatic error bars	Enhanced programming features including IF-THEN statements, FOR loops, GOTO statements, and user-defined functions
Universal Graphics Inc., Burlingame, CA; 415-259-7955; fax, 415-259-7942					
Universal Graphic Library All versions: $995 Circle No. 367	All platforms from PC to mainframes	[IBM PC] MS-DOS 5.0 or later, 2 MB of disk space, 1 MB of RAM	A Fortran routine library that can plot 2- or 3-D world map detail, contours, and more	Available for every (Fortran) computer on the market	The most powerful package on the market for PC platforms

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Visual Numerics Inc., Houston, TX; 800-222-4675; fax, 713-781-9260					
PV-WAVE Advantage Windows NT: $5495 Unix: $6995 Circle No. 368	DEC, HP, IBM, SGI, Sun workstations, DEC Alpha, Intel, MIPS, Windows NT systems	[Windows NT] 75 MB of disk space, 32 MB of RAM; [Unix] 200 MB of disk space, 32 MB of RAM	Visual data analysis product integrating advanced mathematical and statistical analysis functions	Widget toolkit for graphical user-interface development; on-line documentation in Frameview; run-time licensing	Visual data analysis allows users to interactively explore, manipulate, visually analyze, and present large data sets quickly
Visual Solutions Inc., Westford, MA; 508-392-0100; fax, 508-692-3102					
MathViews Micro: $295 PC: $495 Full: $995 Circle No. 369	IBM PC 386, 486, or compatibles	IBM MS/Windows 3.1, 2 MB of disk space, 1.2 MB or 1.44 MB floppy, 4 MB of RAM	Matlab-compatible interactive interpreter of M-files for control systems design and signal processing	Integrated debugger for M-files; 2- and 3-D graphics; DDE, DLL support; autoassign capability for automatic updating of dependent variables	Runs Matlab 3.5 toolboxes; can be enhanced with M-file toolboxes, user-written DDLs
VisSim Micro: $295 PC: $495 Full: $1495 Circle No. 370	IBM PC 286 or better, Unix/X RISC systems	[IBM PC] MS/Windows 3.X, 1 MB of disk space, 1.2 MB or 1.44 MB floppy, 2 MB of memory; [Unix] 3 MB of disk space, floppy drive or 1/4-inch tape, 8 MB of memory	Visually programmed systems design environment for multirate, linear and nonlinear dynamical systems; concurrent static optimization is supported; Matlab interface; DLL, DDE support, add-ons for C-code generation	Support for transfer function blocks, FFT plots and solution of stiff equations	Allows user to write add-ons via DLL capability in MS/Windows; neural networks, real-time data acquisition, discrete-event and queue simulation available
VisSim/DACQ $299 Circle No. 371	IBM PC 286 or better	IBM PC MS/Windows 3.X, 1 MB of disk space, 1.2 MB or 1.44 MB floppy, 2 MB of RAM	A combination of Micro-VisSim and VisSim/RT for data acquisition and hardware in the loop control	Support of Metra Byte, Data Translation, Strawberry Tree, Advantech computer boards; support for multiple data acquisition cards from different vendors used simultaneously	Can communicate with operator interface software via DDE
VisSim/RT $250 Circle No. 372	As above	As above	A real-time add-on to VisSim; performs data acquisition and supports hardware in loop control	As above	As above

A/D=analog to digital (conversion); CAD=computer-aided design; CGM=Computer Graphics Metafile, a binary coding format of the American National Standards Institute; DDE=dynamic data exchange; DLL=dynamic link library; DSP=digital signal processing; EPS=Encapsulated PostScript; FFT=fast Fourier transform; FIR= finite impulse response; FPU=floating-point unit; GPIB=general-purpose interface bus; GUI=graphical user-interface; HP= Hewlett-Packard workstations; HPGL=Hewlett-Packard Graphics language; IBM PC= IBM PCs and compatibles; IIR= Infinite impulse response; ISA=Instrument Society of America; LPC=linear predictive coding; Mac=Macintosh; OLE=object linking and embedding; SGI=Silicon Graphics Inc.; SQC=statistical quality control; Sun= Sun workstations; VHDL=very high-speed IC hardware description language; WAV=Microsoft word format for waveform data.

Data analysis

(Continued from p. 61)

changes over time. These movies can pack an unbelievable amount of information collected from hours of high-speed calculation into a few minutes of play, saving engineers a lot of time.

FRESH DEVELOPMENTS. Few completely new products were introduced last year, as the table indicates. Most developers spent the year upgrading existing products, adapting them to new operating systems, and equipping them with visualization tools.

As engineers and scientists are well aware, graphical data analysis and symbolic notation are best performed with an interface that supports them, like Microsoft Windows, Mac OS, and Motif under Unix.

The proliferation of visualization and exploratory features in data analysis software reflects the growing popularity of these techniques among engineers and other users. New image analysis packages for Windows enabling users to identify objects by their shape and density are sure to please engineers. Not so long ago, the best image analysis software ran only on the Macintosh. The MathWorks Inc. has enhanced Matlab's Image Processing Toolbox in a big way, making it one of the best-known new Windows packages.

New products include Diamond by BMDP Statistical Software Inc., a data analysis and visualization tool for Unix, developed at the IBM Thomas J. Watson Research Center, Yorktown Heights, NY. Diamond is designed to handle immense data sets and displays a wealth of 3-D graphics. One of Diamond's most helpful features is its ability to display N-dimensional data in the form of arrays of 2- and 3-D graphics, while maintaining links between all the data in all the graphics. Another recent entry is STATlab by SLP, a Windows tool designed for EDA and statistics. Engineers are using STATlab to analyze the load factors of telecommunications networks in countries around the world, and to display their results on maps.

During the past year, most developers either announced first-time Windows versions or enhancements to recent releases for MS-Windows. Systat, Monarch, DADiSP, SigmaPlot, and S-Plus, for example, now support Windows. Users laud the availability of scientific software for the tremendously helpful Windows: engineers believe almost unanimously that software with a graphical user-interface dramatically reduces training and learning time. In addition, Windows standardizes data and graphics formats to help move data and graphics between applications with many fewer hindrances than under DOS. Taking Windows support even further, HEM Data Corp. announced support for dynamic data exchange (DDE), a technique for linking files and applications under Windows that automates data sharing between its SnapMaster data acquisition program and other packages.

Spyglass Inc. has taken steps to help its users combine Dicer's and Transform's visualization power with the computational strengths of Mathematica using MathLink. A notable development by Wolfram Research Inc., MathLink lets third-party software developers create links into Mathematica. National Instruments, too, has added MathLink support to the LabView family of data acquisition and analysis products; the addition gives engineers who capture data ready access to Mathematica for advanced mathematical analysis.

More good news is that prices have remained affordable, and in a few cases dropped, if somewhat unevenly. Most tools are priced fairly, making it easier to justify purchases in these tough economic times. As the U.S. economy worsened, the number of special promotional offers and discounts on software increased. For example, Poly Software International promoted its $495 retail PSI-Plot at prices as low as $69.95. But as corporate purse strings loosen, these deep discounts on specialized scientific software will probably disappear.

Packages still differ greatly in terms of

their range of features, speed, and ease of use. Data analysis tools can be subdivided into a number of areas, each with its own set of competitive products. For instance, prices of visualization products for Unix range over an order of magnitude, from $595–$995 (for Spyglass' Transform and BMDP's Diamond) to $6995 (for Visual Numeric's PV-Wave).

STRATEGIC ALLIANCES. Overall, the corporate landscape in data analysis software has undergone many upheavals in the past year, and the change bodes well for engineers who depend upon mathematics software. Most notable are the mergers, acquisitions, and strategic partnerships. Research Systems Inc., Boulder, CO, vendors of IDL and developers of high-end visualization tools, purchased Precision Visuals Inc., developers of PV-Wave, a high-end visualization tool. In addition, Waterloo Maple Software, developer of Maple V for symbolic mathematics, has licensed its symbolic mathematics kernel to The MathWorks, developer of Simulink and Matlab; Mathsoft Inc., developer of Mathcad; and Visual Numerics, vendor of PV Wave. The licensing will enable engineers who use these packages to take full advantage of Maple's symbolic math libraries.

Meanwhile, Wolfram Research has signed up SpyGlass Inc., developer of Transform; Silicon Graphics, El Segundo, CA, developer of Explorer; and National Instruments, Austin, TX, developer of LabView, to create links between their products and Mathematica. Most recently, Mathsoft announced the acquisition of Stat-Sci, developer of S-Plus. These alliances will give engineers access to more statistical, mathematics and visualization software from within their preferred software package.

COMING: PACKAGES FOR WINDOWS/NT. Expect to see continued development for Unix and rapid availability of the most popular packages for Windows/NT. Data analysis software is, by its very nature, extremely compute intensive. It will therefore benefit greatly from 32-bit operating system environments like Unix and Windows/NT. While Windows/NT has just been released, it is clear that most developers will be able to migrate their applications to it with little difficulty, and reap significant benefits for users in the areas of memory management and computational speed. Developers are also looking to harness the speed of new hardware such as Digital Equipment's Alpha, IBM's Power PC, and Intel's Pentium architecture.

Currently, most scientific visualization requires users to select the technique of analysis they will use to explore their data. For example, to fit a curve to data with most of today's data analysis programs, the user selects a method (such as linear regression) from a menu, and then analyzes residuals. The programs depend upon the user choosing the right technique. With even greater interactivity and smart software, the computer can guess at a few good alternative views and reveal unexpected results. For example, TableCurve, by Jandel Scientific, will automatically choose the best regression technique from its large portfolio of fitting options. The approach is known as computational steering, because the software in a way does the "driving." In the future, expect to see programs that implement these concepts much more broadly.

ROOM FOR VIRTUAL REALITY. Engineers will have the power to go beyond simply graphing numerical data and "step inside" their data and equations—imagine walking through a function, in an interaction that combines touch, hearing, and vision and replaces the traditional monitor, keyboard and mouse interfaces. Immersion technology is driven by mammoth commercial markets for games and entertainment, so it is only a matter of time before more immersion tools become available for data analysis software.

Multimedia and compact-disc ROM (CD-ROM) data is an emerging area of general computing that will surely have an effect on data analysis, but products will not be seen any time soon. The multimedia contribution

is most likely to come in the area of audiovisual help and documentation, computer-based training, and new visualization methods, including full-motion video and stereo sound. Engineers will soon probably be able to access huge engineering databases, papers and journals on-line or from a CD with great ease.

There is no *caveat emptor* here. Most of the programs have been developed by dedicated professionals, with backgrounds in mathematics, statistics, and engineering. Their tools derive from years of experience doing what engineers do. But while there is rarely a need to be concerned about the accuracy of programs, any purchase should involve a discussion of each developer's approach to getting the right answer.

Surprisingly enough, in a few cases—usually extreme ones—answers vary. The potential user of a tool should understand the tool's approach. Especially important is numerical precision: some packages use 32-bit mathematics while others use 64 or even 80 bits. Programs such as Systat will throw out cases where data is missing and will compute results based on the remaining data; other programs ignore missing values or resort to means and averages.

The broad range of products available does not indicate a new market waiting for a shakeout. Rather, it reflects increasing specialization by developers. Profit from this fact when making your decision to buy. The existence of many competing products also ensures that constant new development is a high priority of the software companies. The best data analysis programs are not a bother to use, not least because of their graphical user-interfaces.

ON-LINE HELP, USER'S PROGRAMMING. This year's crop of new products and upgrades boast extensive on-line help systems, good documentation, rapid performance, and other features that render them useful to scientists and engineers. The latest data analysis software runs on a range of computer platforms, from low-end personal computers to high-performance workstations, using DOS, Windows, Mac O/S, and the many flavors of Unix; IDL from Research Systems Inc. is a case in point [see Software Reviews, *IEEE Spectrum,* August, p. 15].

All products include features for performing numerous complex mathematical functions, statistical analysis and scientific graphics, but some also offer users powerful high-level languages with which to create their own analyses. Systat's macro language lets users create complex programs to perform all the steps needed to combine data sets, transform data, run statistical analyses, and plot results.

Unique among recent entries is the BBN/Cornerstone package from BBN Software Products. It incorporates the latest advances in object-oriented, client-server technology. The package's Workmap diagram automatically captures each step in the course of an analysis and displays the steps as icons. With a simple point and click a user may resume work at any step or perform the same analysis with new data. The diagram also makes it easier to share the analysis process with co-workers in a work group.

With so many options in every area, it is impossible to pick an overall winner. Data analysis software should be able to perform the calculations the user needs, and have a range of features that make it easy to use, including pull-down menus, a graphical user-interface, on-line help, and comprehensive documentation.

It is best to look for programs that have the graphics power not just to plot but also to visualize the data. Often it is useful if the program one chooses, if it is used often, has a high-level language, macro, or batch capability, so that analyses may be repeated quickly and easily.

A precaution: be sure that there is enough memory and hard disk to meet the needs of these programs. Requirements vary widely, and there is no correlation between the number of features and number of requirements. For example, S-Plus requires 8 MB of RAM and up to 25 MB of disk space, while STATlab requires 4 MB of RAM and 2 MB of disk space. The ultimate scientific data analysis tool kit should include at least a mathematics package such as Mathcad or, for more advanced requirements, Matlab; a statistical analysis tool such as Systat, STATlab, or S-Plus; and such exploratory data analysis or visualization tools as Transform, PV Wave, or Data Desk.

All the same, don't rule out some packages that have fewer exploratory and visualization features, like Abacus Concepts' StatView 4.0, or Jandel Scientific's SigmaStat. Their combination of the most popular features, ease of use, and low cost may make them the right choice.

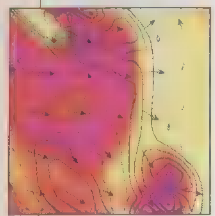
Also, don't be swayed by the latest discount offer on a seemingly useful package. First, there's no point saving hundreds of dollars on a package that will not do the job. Also, factor in learning time and technical support. The time spent learning a product can easily be worth much more than the software itself. Look at software the same way you look at other investments your company makes: what's the payback? If spending $10 000 on the best solution could save the company millions, it's certainly worth it.

Above all, talk to engineers who are working on similar problems. Profit from their research in deciding which program to choose. Better yet, once the program arrives on your desk, you'll have someone to turn to for help. ◆

ABOUT THE AUTHOR. Ken Kornbluh is vice president of SciTech International, a leading distributor and publisher of scientific and technical software. His e-mail address is 74710,2400@CompuServe.Com.

Efficient data acquisition

Visual programming techniques and support for multiple platforms improve productivity in a slew of data-acquisition applications



The field of data acquisition—the use of instruments to automate the sampling of analog variables, digitize the samples, and either store the results for later analysis or analyze them on the fly—is evolving vigorously.

One factor is the VXIbus; its growing acceptance is extending the frequency range of this instrumentation still higher. At the same time, portable yet highly competent systems are becoming practical, now that newly compact data-acquisition hardware is being combined with laptop computers.

Michael J. Riezenman Senior Editor

In addition to accommodating these hardware developments, modern data-acquisition software also keeps up with the times in other ways. As a glance at the accompanying table makes clear, graphics—especially three-dimensional graphics—is what distinguishes today's packages from those of just a few years ago. It permeates the entire data-acquisition field, from programming methodologies to the presentation of data.

Also very new to many of today's data-acquisition packages, and a capability that simply did not exist even a few years ago, is support for digital signal-processing (DSP) boards. DSP boards and software together can reduce data in real time as it is acquired. It becomes practical, for example, to construct acoustic test and measurement systems for characterizing audio equipment and environments.

Other recent trends include the elimination of limits on file size (other than those imposed by the hard disk, of course) and stronger support for mice, object linking and embedding (OLE), dynamic data exchange (DDE), and a number of other Windows artifacts.

While most packages are still married to one type of platform (IBM PC or equivalent, Unix workstation, or Macintosh computer), a sizable number pay suit to two or even all three basic platform types. So, in reading this table, be sure to check the "Platform" column; it could be good news.

As in previous *IEEE Spectrum* focus reports on software for engineers and scientists, the table includes columns for recent enhancements and outstanding features. New this year is a brief description of each product, which it is hoped will be useful not just to newcomers to the field but also to veterans who want to learn about packages to which they have never been exposed.

If a package seems to be of interest, additional information may be obtained by circling the appropriate number on the reader service card in this issue or phoning or faxing the vendor. But first check To Probe Further on p. 88; it may provide even better sources of information. ✚

Data acquisition

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
BBN Software Products, Cambridge, MA; 617-873-5000; fax, 617-873-6153					
RS/Series Software $595+ RS/1: optional modules extra Circle No. 374	DEC RISC/ Ultrix, VAX/ VMS; HP/UX; IBM DOS PCs and compatibles, IBM RS/6000; Sun Sparc-Stations	[386-PC or above] ≥1 MB of base memory, plus 1 MB of extended memory (RAM); [VMS and Unix machines] 40 MB of disk space, 16 MB of RAM	RS/1 is a menu-driven data analysis and graphics package that provides integrated statistical and quality analyses for manufacturing, engineering, and research; RS/QCA II provides a full range of powerful, easy-to-use SQC functions, including control charts	—	RS/1 includes data management, statistics, graphics, curve-fitting, modeling, and report-generating capabilities; has a built-in programming language for customized applications
BBN Systems & Technologies, Cambridge, MA; 800-84-Probe; 617-873-2120; fax, 617-873-2205					
BBN/Probe $13K (Volume discounts) Circle No. 373	Sun, HP, SGI, DEC VAX, DECstation, DEC Alpha	[Sun OS 4.1] Solaris 2.X, HP-UX, SGI/IRIX, Ultrix Open VMS, 25 MB of disk space, 15–20 MB of swap space	Interactive time-series data reduction, analysis, and graphics system; allows user direct access to large data sets	HP, SGI, and Alpha; open VMS versions; digital filter design; polar plots, data access, and code optimization enhancements	Can access and analyze data from telemetry and recording systems; 1553 messages; simulations
CoHort Software, Berkeley, CA; 800-728-9878; 510-524-9878; fax, 510-524-9199					
CoVis $395 Circle No. 375	IBM PC or compatible	MS-DOS 2.0 or later, 2 MB of disk space, 640 kB of RAM	Makes animated 2- and 3-D scientific graphs of large data sets	Able to work with data files of any size, given adequate hard disk space	Lets user look at large data sets in new and unusual ways
Computer Marketing Co. (PVT) Ltd., Lahore, Pakistan; (92+42) 571 1701/5; fax, (92+42) 571 2005					
Soft Scale 9999 Pak. Rs. Circle No. 376	IBM PC DOS, MS-DOS, DR-DOS	[IBM PC/XT/AT-compatible] 640 kB of RAM	Converts fractional weights from grams to the Tola, Masha, and Rati systems; useful for gold market operations	Prompt result-oriented formulas; error-correction code	Maintains database of all transactions; calculations up to 16 decimal places
CS Control Software Oy, Helsinki, Finland; (358+0) 67 67 44; fax, (358+0) 67 00 77					
GRED 15 150 FIM excluding VAT Circle No. 378	IBM PC: 386 or better	MS-DOS 5.0 or later, 10 MB of disk space, 4 MB of RAM	Graphical PC-supervisor program; connects to most PLCs	More drivers added; connection to a simulation system	Program includes recipes, trends, and report generator

READER SERVICE (CIRCLE NUMBERS)

1 PRODUCT AND ADVERTISING INFORMATION

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2 ADDITIONAL COMMENTS

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					Comments and features
					GUI; interface to cybernetic and other industry-standard PLCs; user-definable screens
					Educational discounts available
					Based on HP VEE; lets user create application programs without writing code; run-only version for use on multiple units available for $495
		expansion slot in PC			Easy to use; builds on the graphical design and programming paradigm of Visual Basic; expands the use of Microsoft Visual Basic for Windows to labs, R&D, engineering, and scientific applications
Dianachart Inc., Rockaway, NJ 07886; 201-625-2299; fax, 201-625-2449					
Insta-Trend System $755+ Circle No. 382	IBM PC	MS-DOS 3.2 or later, 2 MB of disk space, 640 kB of RAM	Real-time graphics data acquisition; PID and PLC control; replay calculations; user-generated graphics and custom reports; strip-chart capabilities	Voice-phone alarm and interrogation; user-specified report; format and content	No programming required; context-sensitive help; lets user set everything up at menus

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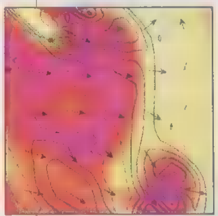

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RS/Series Software $595+ RS/1: optional modules extra Circle No. 374	DEC RISC/ Ultrix, VAX/ VMS; HP/UX; IBM DOS PCs and compatibles, IBM RS/6000; Sun Sparc-Stations	[386-PC or above] ≥1 MB of base memory, plus 1 MB of extended memory (RAM); [VMS and Unix machines] 40 MB of disk space, 16 MB of RAM	RS/1 is a menu-driven data analysis and graphics package that provides integrated statistical and quality analyses for manufacturing, engineering, and research; RS/QCA II provides a full range of powerful, easy-to-use SQC functions, including control charts	—	RS/1 includes data management, statistics, graphics, curve-fitting, modeling, and report-generating capabilities; has a built-in programming language for customized applications
BBN Systems & Technologies, Cambridge, MA; 800-84-Probe; 617-873-2120; fax, 617-873-2205					
BBN/Probe $13K (Volume discounts) Circle No. 373	Sun, HP, SGI, DEC VAX, DECstation, DEC Alpha	[Sun OS 4.1] Solaris 2.X, HP-UX, SGI/IRIX, Ultrix Open VMS, 25 MB of disk space, 15–20 MB of swap space	Interactive time-series data reduction, analysis, and graphics system; allows user direct access to large data sets	HP, SGI, and Alpha; open VMS versions; digital filter design; polar plots, data access, and code optimization enhancements	Can access and analyze data from telemetry and recording systems; 1553 messages; simulations
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CoVis $395 Circle No. 375	IBM PC or compatible	MS-DOS 2.0 or later, 2 MB of disk space, 640 kB of RAM	Makes animated 2- and 3-D scientific graphs of large data sets	Able to work with data files of any size, given adequate hard disk space	Lets user look at large data sets in new and unusual ways
Computer Marketing Co. (PVT) Ltd., Lahore, Pakistan; (92+42) 571 1701/5; fax, (92+42) 571 2005					
Soft Scale 9999 Pak. Rs. Circle No. 376	IBM PC DOS, MS-DOS, DR-DOS	[IBM PC/XT/AT-compatible] 640 kB of RAM	Converts fractional weights from grams to the Tola, Masha, and Rati systems; useful for gold market operations	Prompt result-oriented formulas; error-correction code	Maintains database of all transactions; calculations up to 16 decimal places
CS Control Software Oy, Helsinki, Finland; (358+0) 67 67 44; fax, (358+0) 67 00 77					
GRED 15 150 FIM excluding VAT Circle No. 378	IBM PC: 386 or better	MS-DOS 5.0 or later, 10 MB of disk space, 4 MB of RAM	Graphical PC-supervisor program; connects to most PLCs	More drivers added; connection to a simulation system	Program includes recipes, trends, and report generator

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Cybernetic Research (PVT) Ltd., Lahore, Pakistan; (92+42) 571 1004/5; fax, (92+42) 571 1003					
CyPRIS 29 500 Pak. Rs. Circle No. 377	IBM PC: 386 or better	MS-DOS 5.0 or later, VGA color monitor, 10 MB of disk space, 2 MB of RAM	Gathers data from remote PLC; logs data and analyzes it for various efficiency and status reports; real-time control; as well as production management	Multilingual user-interface supports Arabic, Urdu, Russian; Yokogawa PLC interface	GUI; interface to cybernetic and other industry-standard PLCs; user-definable screens
Data Description Inc., Ithaca, NY; 607-257-1000; fax, 607-257-4146					
Data Desk 4.1 $595 Circle No. 379	Mac	System 6.0.8 or later, 1 MB each of disk space and RAM	Interactive and graphical statistics package combining exploratory data analysis tools with traditional statistics procedures	Eliminated 32 000-case limit; added many new statistical features and visualization tools	Educational discounts available
Data Translation Inc., Marlboro, MA; 508-481-3700; fax, 508-481-8620					
DT VEE for Windows IBM PC: $1995 Circle No. 380	IBM PC: 386, 486 recommended	MS-DOS 5.0 or later; MS Windows 3.1 or later; Super VGA, math coprocessor, 12 MB of disk space, [illegible] MB of RAM, mouse, 3.5-inch floppy, I/O board and driver supported	A complete icon-based visual programming package for real-world data acquisition and analysis; easy to learn and use, intuitive approach to programming	Support for high-performance data-acquisition boards under the DT Open-Layer specification	Based on HP VEE; lets user create application programs without writing code; run-only version for use on multiple units available for $495
VB-EZ Visual Basic Programming Tools for Windows $195 Circle No. 381	IBM PC: 386 or better	MS-DOS 3.3 or later; MS Windows 3.1 or later; Microsoft Visual Basic for Windows 2.0 or later, professional edition recommended; EGA, VGA, or compatible display; one hard disk, one floppy; ≥4 MB of RAM; ≥1 expansion slot in PC	Acquires, analyzes, displays data from data acquisition board at high speed; includes example programs to begin analog and digital I/O with no programming; custom controls for I/O minimize programming	Two custom controls significantly reduce programming and allow high-speed plotting under Windows; data acquisition custom controls manage all aspects of the hardware interface	Easy to use; builds on the graphical design and programming paradigm of Visual Basic; expands the use of Microsoft Visual Basic for Windows to labs, R&D, engineering, and scientific applications
Dianachart Inc., Rockaway, NJ 07886; 201-625-2299; fax, 201-625-2449					
Insta-Trend System $755+ Circle No. 382	IBM PC	MS-DOS 3.2 or later, 2 MB of disk space, 640 kB of RAM	Real-time graphics data acquisition; PID and PLC control; replay calculations; user-generated graphics and custom reports; strip-chart capabilities	Voice-phone alarm and interrogation; user-specified report; format and content	No programming required; context-sensitive help; lets user set everything up at menus

Data acquisition *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Dux Software Corp., Los Altos, CA; 415-967-1500, fax; 415-967-5528					
XPlot $695 Circle No. 383	Sparc-based systems with Sun O/S 4.1.3 or Solaris 2.X	Open Windows 2.0, 3.0; 24 MB of swap memory, 3 MB of disk space, 12 MB of RAM, color/monochrome PostScript printer	Presents ASCII data in columnar format and shows it in *x,y* plots	Error bars, 24 fonts, polynomial curve-fitting, expanded grid controls, command-language batch format, additional math features, and more	Legend support with interactive placement; symbol color and modular controls; drag-and-drop support for data, batch, default, and canvas files
Entropic Research Laboratory, Washington, DC; 202-547-1420; fax, 202-546-6648					
ERS-2000 1.4 $4990–$10 780 (Academic discounts) Circle No. 384	Sun, SGI, HP, DEC, IBM, Unix workstations	Unix and X-Windows, 12 MB of disk space, 16 MB of RAM	Real-time dual-channel data acquisition, analysis, and display over X-Windows networks; supporter sample rates up to 100 000 samples per second	Support for single mouse-click event logging; support for SCSI-based I/O and SGI built-in I/O	Automatically checks validity of instrument settings; real-time spectrogram displays
ESPS 5.0 $5990 (Academic discounts, site licenses) Circle No. 385	HP, DEC, SGI, Sun, Unix workstations	Recent vendor versions of Unix and X-Windows, 85 MB of disk space, 8 MB of RAM	Unix-style signal-processing tool kit; facilitates rapid prototyping and custom program development; written in C; source code available	Analysis/synthesis programs; new IIR and FIR filter design techniques	Built-in support for all workstations; audio I/O support for NIST and LDC databases; VQ, DTW, and maximum likelihood pattern classification programs
HTK 1.5 $4300 (Academic discounts, site licenses) Circle No. 386	Sun, HP, SGI, DEC workstations	Recent vendor versions of Unix and X-Windows, 25 MB of disk space, 4 MB of RAM	Toolkit for building and testing continuous-density hidden Markov model classification systems	Toolkit for speaker-independent continuous speech recognition on Darpa Resource Management Task; toolkit for automatic transcription alignment	Extensible, modular library design simplifies development of user-written extensions; suitable for speech recognition, speaker verification, language identification, and more
waves+ 5.0 $3990 (Academic discounts, site licenses) Circle No. 387	Sun, HP, SGI, DEC Unix workstations	Recent vendor versions of Unix and X-Windows, 38 MB of disk space, 16 MB of RAM	Interactive signal analysis and visualization software; built-in spectrogram and audio I/O support; specialized interfaces to support interactive signal labeling and spectrum analysis	High-resolution, publication-quality graphics output; built-in and user-definable tool bars and key-binding support; graphical interface for building menus	Full control over waves+ by other programs; interface allows both visible and audible comparisons
Famous Engineer Brand Software, Richmond, VA; 804-222-2215; fax, 804-226-1934					
digiMatic PC v1.1, Mac V2.05 $249 ($149 academic) Circle No. 388	IBM PC: 386 or better Mac: all	[IBM PC] Windows 3.1, 1.2 MB of disk space; [Mac] System 6.0.x–7.x, 300 kB of disk space, 1 MB of RAM	Recovers underlying *x,y* data from existing charts and graphs; scanner useful; tablets supported	Version for Windows on PC	Point-and-click digitizing or full AutoScan recovery; linear-log axes in any combination; exports data in standard tab-delineated format, portrait or landscape
Fluke Corp., Everett, WA, 800-44-FLUKE; fax, 206-356-5116					
MET/CAL $5950 Circle No. 389	286 100% PC-AT-compatible, 386 recommended	MS-DOS 3.3 or later (5.0 recommended), 40 MB of disk space (200 MB recommended), 640 kB of RAM, one serial port (three recommended), one parallel port, two IEEE-488 interface cards	Uses a PC as a system controller to calibrate a broad range of instruments and automate information collection and reporting; supports ISO 9000 traceability and documentation requirements	Controls additional calibration instruments (Fluke 5790, Fluke PM 6680, Tektronix SG 5030); includes new procedures and user's manual	Automatically calculates error, percent of tolerance, and test uncertainty ratio; drives wide range of calibration instuments
MET/Track $6450 Circle No. 390	286 (IBM PC AT, PS/2, or 100% compatible)	MS-DOS 3.3, hard disk drive (size determined by formula), 640 kB of RAM, parallel port	Handles metrology property management; supports traceability requirements, incl. ISO-9000 and MIL-STD-45662A, through structured data collection and powerful searching, sorting, and reporting capabilities	New manual; enhanced customization	Network-capable; calibration by interval or by usage
HEM Data Corp., Southfield, MI; 313-559-5607; fax, 313-559-8008					
Snap-Master for Windows Data Acq. Module $995 Circle No. 391	IBM PC/AT or better	MS-DOS 3.1 or later, Windows 3.0 or later, Windows-compatible display, 4 MB of RAM, compatible I/O hardware	Data acquisition; high-speed data streaming to disk; near real-time plotting; storage and retrieval; acquires low- and high-speed data simultaneously with multiple I/O sources	DDE support; network connectivity and Net DDE Support in Windows for workgroups; built-in context-sensitive on-line help	Available in three compatible modules: data acquisition, general analysis, and frequency analysis
Hewlett-Packard Co., VXI Instruments Div., Loveland, CO; 303-679-2623; fax, 303-679-5952					
HP VEE Graphical Programming Language Development versions– Unix: $5700, Windows: $1995 Circle No. 392	IBM PC: MS-Windows Sun: SparcStation HP Series 700 and 300	[IBM PC] 15 MB of disk space, 12 MB of RAM; [Unix platforms] 15 MB of disk space, 16 MB of RAM	A complete graphical programming environment that controls any IEEE-488, RS-232, or VXI instrument; programs for instrument I/O, analysis, and display are created by visually linking executable objects	Full support of Sun and MS-Windows platforms; addition of non-HP instrument drivers and test sequencing	Run-only versions available for $1750 (Unix) and $495 (Windows)

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Hyperception Inc., Dallas, TX; 214-343-8525; fax, 214-343-2457					
AMPS (Acquisition, Measurement, Processing and Storage) $1495 Circle No. 393	IBM PC 386 or better	DOS 3.1 or later, Windows 3.1, 2–3 MB of disk space (plus memory space to record data), 4 MB of RAM	Uses one of 21 DSP/acquisition boards to make a digital recorder, spectrum analyzer, and oscilloscope	Improved triggering capability, snap-in digital filters for all instruments, more boards supported	User interface is similar to traditional instruments but with the advantages of a PC
Intec Controls Corp., Walpole, MA; 508-660-1221; fax, 508-660-2374					
Paragon 500 $2200–$10 200 Circle No. 394	IBM PC: MS-DOS	DOS 3.x or later, math coprocessor, EGA/VGA, 30 MB of disk space, 640 kB of RAM, mouse	For basic Scada applications	Additional I/O drivers, higher I/O performance	Intuitive design tools, graphical programming, multitasking environment
Paragon 550 $3200–$14 700 Circle No. 395	As above	As above	Industrial automation software for process monitoring, control, and information management	Higher I/O performance, string handling, TCP/IP support	Plant computer connectivity, remote links via modem, dumb terminal support
Paragon TNT $1050–$16 800 Circle No. 396	IBM PC: OS/2 (Windows NT soon)	486DX/33 MHz, OS/2 v2.x, VGA, 120 MB of disk space, 12 MB of RAM, mouse	Client-server Scada software based on 32-bit platform for plant floor applications	Recipes client, quick reports client, engineer interface for on-line diagnostics and displays	Fully windowed interface, intuitive design tools, SQL/relational database interface, open links to third-party software
Integral Signal Processing, Austin, TX; 512-346-1451; fax, 512-346-8290					
Integrated Signal Analysis (ISA) IBM PC: $695 Sun or DEC: $2950 Circle No. 397	IBM PC compatibles, Sun Sparc, DEC VAX workstations	[IBM PC] MS-DOS 4.0 or later, 10 MB of disk space; [Sun] Sun OS 4.1 or later, 15 MB of disk space; [DEC] VMS V5.0 or later, 15 MB of disk space	Performs higher-order spectral analysis—bispectrum, bicorrelation, tricorrelation	Built-in publication-quality graphics tailored for higher-order spectral analysis	Wave number-frequency spectrum; phase-sensitive complex demodulation provided; ISA library and application source code provided for workstation version
Intelligent Instrumentations Inc., Tucson, AZ; 800-685-9911; fax, 602-573-0522					
Signalyzer $495 Circle No. 398	IBM PC: 386 or better	Windows 3.1 or later, intelligent instrumentation data acquisition or DSP board, 2 MB of disk space, ≥2 MB of RAM	Windows-based data acquisition, analysis, and display software; captures 1–32 channels of data at sample rates up to 10 MHz	New product	Emulates oscilloscope and spectrum analyzer; real-time streaming to disk; script files for automating frequently used commands

Circle No. 202

Data acquisition *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Intelligent Instrumentations Inc., Tucson, AZ; 800-685-9911; fax, 602-573-0522 (continued)					
Visual Designer $995 Circle No. 399	IBM PC: 386DX or better	Windows 3.1 or later, VGA 10 MB of disk space, ≥4 MB of RAM (8 MB of RAM required for DMA)	Application generator for PC-based data acquisition, test, measurement, and control; custom software created with no programming	New product	Graphical, block-diagram development environment; real-time displays and user controls/interfaces
Keithley Instruments Inc., Taunton, MA; 508-348-0033; fax, 508-880-0179					
Asyst 4.01 $1995 Circle No. 400	IBM PC XT/AT: 386, 486, or better, IBM PS/2	MS-DOS 3.0 or later, math coprocessor, 5 MB of disk space, 1 MB of RAM	Programming language designed for data acquisition, data analysis, and graphics	Supports larger programs and data sets; added counter-time support; added new analysis/filter functions	Additional options on copy protection and run-time system development now available
Easytest LX $695 Circle No. 401	IBM PC XT/AT: 386, 486	MS-DOS 3.0 or later, math coprocessor, EGA or better, 2 MB of disk space, 2 MB of RAM	Utility program for data capture, display, and test sequence automation	Stored sequences can be eight times larger; faster strip chart; expanded help	Also available as Easytest AG ($195) for acquisition and graphics only (no test sequence automation)
Viewdac 2.1 $1995 Circle No. 402	IBM PC-compatible: 386, 486, or better	As above, but 15 MB of disk space, 6 MB of RAM	Windows-oriented package with integrated data acquisition, analysis, and graphics enables complex data acquisition applications without programming	Speeded up sequence execution; added analysis functions; added improved GPIB support	Supports pre-preemptive multitasking, and interactive post-acquisition analysis
KineticSystems Corp., Lockport, IL; 815-838-0005; fax, 815-838-4424					
Instinct $3510 Circle No. 403	VAX VMS, VAX Ultrix	Workstation with 15 MB of RAM	Icon-driven data acquisition for Camac (Computer Automated Measurement and Control IEEE-583)	Support for more I/O modules; added support for Ultrix	No programming required
Interface to LabView for Camac and VXI $495 Circle No. 404	IBM PC: 386 or better	Windows, LabView 2.5.2 or later, 8 MB of RAM	Graphical programming link to LabView software for Camac and VXIbuses	New product	—
Laboratory Technologies Corp., Wilmington, MA; 800-879-5228; fax, 508-658-9972					
Labtech Notebook $995 Circle No. 405	IBM PC XT/AT: DOS, IBM 386 or better, Windows	MS-DOS 2.0 or later, 2 MB of memory, Windows 3.1, 4 MB of memory	Real-time data acquisition and display; records in disk file for analysis; handles many input/output types and calculations	Client/server networking for remote monitoring and control; operator interface adds knobs, buttons, sliders; universal driver set for all popular I/O devices	DOS, Windows versions shipped together; no programming; supports hundreds of data I/O devices
MicroCal Software Inc., Northampton, MA; 413-586-2013; fax, 413-585-0126					
Origin $495 (U.S.) $600 (overseas) Circle No. 406	IBM PC or compatible: 286, 386, 486	Windows 3.0, ≥2 MB each of disk space and RAM	Graphics and data analysis in Windows; open-ended architecture supports add-on modules; built-in scripting language and publication-quality graphics	3-D/contour, data acquisition, and user-interface modules; OLE support; support for GPIB, RS-232, and other PC plug-in boards	Data acquisition modules continuously being developed; multilayered plot format; performs data analysis such as FFT and curve-fitting
National Instruments, Austin, TX; 512-794-0100; fax, 512-794-8411					
LabVIEW IBM PC and Mac: $1995 Sun: $3995 Circle No. 407	IBM PC: Windows; Mac, Sun SparcStation	[IBM PC] 386/25, Windows, 387 coprocessor, 16 MB of disk space, 8 MB of RAM; [Mac] any, 4 MB of memory; [Sun] SparcStation 1, 12 MB of disk space, 24 MB of RAM, 32 MB of disk swap space	Analysis library with functions for array and matrix manipulation, complex arithmetic, statistics, fast Fourier transforms, curve-fitting, digital filters, real and complex vector and scalar operations	Portability among all three platforms; measurement-based VIs can assume real-world time-domain signal input directly to data acquisition VIs; new 3-D graph and chart functions	Graphical programming shortens development; graphical language compiler speeds execution; custom GUI capabilities; user can program different types of instrumentation hardware
LabWindows Full development system: $1495 Circle No. 408	IBM PC: DOS-based	IBM PC/AT, EISA, PS/2 or compatible with 286 coprocessor, numeric coprocessor recommended, EGA, VGA, Super VGA, or Hercules adapter, 8 MB of disk space, ≥2 MB of RAM	Set of software tools and libraries for developing programs in C and Basic for data analysis, instrument control, data acquisition and presentation; can control GPIB, VXI, RS-232 instruments; user interface library has functions for creating multiplot graphs, strip charts, bar charts, and scatter plots	CodeBuilder user interface for automatically designing and building programs; graph and cursor controls	MS-DOS–based LabWindows C programs can run in LabWindows/CVI programming environment
LabWindows/ CVI IBM PC: $1995 Sun: $3995 Circle No. 409	IBM PC: Windows; Sun SparcStation	[IBM PC] 386/33, MS-DOS 5.0, Windows 3.1, 387 coprocessor, 20 MB of disk space, 8 MB of RAM; [Sun] 20 MB of disk space, 24 MB of RAM, 32 MB of disk swap space	Used to design portable instrumentation applications with C that run under Windows and Solaris; includes ANSI C compiler, linker, debugger, variable-trace display, memory-checking capabilities	Portability between platforms; automatic code generation package; built-in libraries for data acquisition, analysis, and presentation	MS-DOS-based LabWindows C programs can run in LabWindows CVI

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
NeuralWare Inc., Pittsburgh, PA; 412-787-8222; fax, 412-787-8220					
DataSculptor PC version: $495 Circle No. 410	PC/AT: 386, 486	DOS 3.3 or later, DRDOS 6.0, Windows 3.1, 3 MB of disk space, 4 MB of RAM	Accesses, merges, analyzes, displays, and transforms data; includes several features for developing data-oriented models	Automatic data analysis and transformation; improved speed and memory requirements	Simplifies transferring data for neural network development, especially for first-time work
Newport Electronics Inc., Santa Ana, CA; 800-NEWPORT; 714-540-4914; fax, 714-546-3022					
WorkBench PC $995 Circle No. 411	IBM PC: MS-DOS, Mac	[IBM PC AT/XT] MS-DOS, Hercules EGA or VGA, 640 kB of RAM; [Mac] Mac II or SC	Icon-driven data acquisition software	RS-232 support; IEEE-488 support; additional device drivers	—
IoCalc $550 Circle No. 412	IBM PC: MS-DOS Sun: OS/2	[IBM PC AT/ XT or compatible] MS-DOS 3.0 or later, CGA, EGA, VGA, or Hercules; ≥512 kB of RAM [Sun] OS/2 or later	Spreadsheet program can acquire, process, and output analog and digital data in real time	Sun OS/2 support; additional device drivers	True real-time, multitasking data processing; implements control loops, data loggers, digital filters; menu-driven with context-sensitive help
Nivaltec SA, Buenos Aires, Argentina; (54+1) 822 9120; fax, (54+1) 821 3804					
Taurus Display 16, 1050: $250, $750 Board 16, 1050: $750, $1500 Full 16, 1050: $1500, $2500 Circle No. 413	IBM PC-compatible: 386 or better	MS-DOS 3.3 or later, VGA card, 10 MB of disk space, 1 MB of RAM, Microsoft mouse or compatible	Integrated, self-contained solution for data acquisition, supervision, control; set of tools elaborates any kind of application; family of communication drivers available at no extra charge	Virtual variables support structured user database and multimedia enhancements	Modem, radio, and satellite communications; redundant systems; trends, alarms, historic files, events, reports, passwords; block animations, user fonts and symbols, instrument panels; user-defined sensitive zones for triggering recipes, pagelinking; and more; evaluation version for $20
Omega Engineering Inc., Stamford, CT; 203-359-1660; fax, 203-359-7990					
Centrel $198 Circle No. 414	Mac	Macintosh Plus or better, floating-point coprocessor recommended	Data acquisition and control software for the Mac	Additional hardware device drivers; general RS-232 function block	Low-cost, easy-to-use, icon-driven software

Data acquisition *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Omega Engineering Inc., Stamford, CT; 203-359-1660; fax, 203-359-7990 (continued)					
Omega Trend $349 Circle No. 415	IBM AT or compatible: 286, 386, and 486	VGA or better, MS-DOS 3.1 or later, ≥2 MB of disk space, 640 kB of RAM min	Used with analog input plug-in board, turns the computer into a high-speed (7000 samples) strip chart recorder	Additional hardware support	Easy to use, has the look and feel of a traditional strip chart recorder
WaveForm DSP $895 Circle No. 416	IBM PC or compatible: 286 or better	Windows 3.0 or later, 2 MB of disk space, 1 MB of extended memory, mouse or Windows pointing device	WaveForm analysis software may be downloaded from digitizing oscilloscopes, processed in time or frequency domain, then output through arbitrary-waveform generators	Additional hardware drivers	DDE support eases data transfer to and from other Windows applications such as Microsoft Excel
Operation Technology Inc., Irvine, CA; 800-477-ETAP (USA); 714-476-8117 (worldwide); fax, 714-476-8814 (worldwide)					
Power Station Contact vendor Circle No. 417	IBM PC: 386, 486	—	Graphics-intensive simulator with optional capabilities to monitor, simulate, control, and alarm electric power systems	Simulates power systems with on-line load flow, short-circuit, and motor starting; user-modifiable GUI	—
Paladin Software Inc., San Diego, CA; 619-490-0368; fax, 619-490-0177					
MicroTAP 2.1 $299 Circle No. 418	IBM PC or compatible	MS-DOS 211 or later, one floppy disk drive or one floppy and any hard disk drive, 256 kB of RAM	Software serial line monitor; turns PC into communications monitor/debugger	CUA-compliant file management; signal tracing	Time-stamps to the microsecond
Prowave Engineering Inc., Hsinchu, Taiwan; (886+35) [illegible] 96 50; fax, (886+35) 32 67 09					
Signal Doctor NT$135 000 Circle No. 419	IBM PC: 286 or better	MS-DOS 3.0 or later	Vibration/noise FFT analysis	Chinese on-line help; SMS Star model interface; in-field balancing for rotating machinery	Windows 3.1 version
Reaction System Inc., Humble, TX; 800-786-3490; 713-446-5200; fax, 713-446-7800					
AlertICM Industrial Control & Monitoring Software Series Runtime systems: $995+ (current version 5.2) Circle No. 420	IBM PC AT: 386 or 486	DOS 5.0 or later, LIM 4.0 expanded memory driver, VGA, 6 MB of disk space, 2 MB of RAM, parallel printer port; optional: mouse or trackball, touchscreen; choice of four printers	SPC/SQC, historical logging and trending, free-form report generator and scheduler, alarm management, password security, ladder logic control program, display graphics from various desktop programs and AutoCad	Supports most LAN systems, has Microsoft Windows DDE support; separate runtime and development systems; drivers for most PLCs and I/O subsystems	Quick and easy to configure and modify existing applications; fast screen update and communications throughput; uses LaserJet, Proprinter, PaintJet, or color DeskJet printers
Scientific Software Tools Inc., Paoli, PA; 215-889-1354; fax, 215-889-1556					
Driver LINX IVB $395 Circle No. 421	Windows 3.X	IBM 286, 386, 486, MS-DOS 3.1 or later, Windows 3.X, Visual Basic 1.0 or later, 4 MB of RAM	Multitasking, multiuser, DLL data acquisition driver	Source code examples, 500 kB of Windows data acquisition examples; Visual Basic custom controls	Supports A/D hardware from Analogic, ADAC, Data Translation, Advantech, Keithley Metrabyte, Industrial Computer Source, and Computer Boards; version available for development in C, C++
Signalogic Inc., Dallas, TX; 214-343-0069; fax, 214-343-0163					
DSPower $795+ Circle No. 422	IBM 386 or better or Windows-NT–supported platform	MS-DOS 5.0 or later, DOS/Windows 3.1 or Windows NT	Numerous math and DSP functions; supports for DSP/analog hardware; generates source code for Hypersignal macro language, Matlab M files, and C language	Full compatibility with Hypersignal-Macro displays and instruments; Matlab source code generation; additional support for new types of PC-based DSP/analog and multimedia hardware	Block diagram user interface; includes simulation, interactive displays, and real-time instruments and data acquisition; on-line editing and automated tools allow integrated simulation and analysis
Signal Technology Inc., Santa Barbara, CA; 805-899-8300; fax, 805-899-4344					
N!Power Family, Data!Power Developer $5K+ **First!Power** $1K+ (permanent licenses) Circle No. 423	Sun SparcStation, HP 9000/7xx, DECstation, VAXstation, X Window server	15 MB of disk space, 16 MB of RAM, X-Windows device, OpenWindow, HPVue or Motif X toolkit, PostScript, EPS, CGM, HPGL, or PICT hardcopy	Real-time data acquisition, analysis, display; customizable visual programming, menu and command interfaces; self-synchronizing processing; acoustic, biomedical, industrial, embedded, OEM, and client/server applications	Real-time continuous data acquisition with start/stop button; runtime/OEM versions; block diagram controls	OEM flexibility, integration, and interoperability; application development; reads any data files; developer version may be leased for $2.5K; OEM prices available
Stat-Ease Inc., Minneapolis, MN; 800-325-9829; 612-378-9449; fax, 612-378-2152					
Design-Ease Version 3 All versions: $395 Circle No. 424	IBM PC: MS-DOS, Windows Mac: all	[IBM PC] 1 MB of disk space, 640 kB of RAM, EMS-supported; [Mac] System 7.0, 2 MB of disk space, 4 MB of RAM	Sets up and analyzes two-level factorial design of experiments	Added Mac and Windows capability (GUI)	Helps experimenters identify the vital few factors affecting their process or product

(Continued on p. 86)

Data acquisition *(continued)*

Package and price	Platform	Requirements	Brief product description	Recent enhancements	Comments and features
Stat-Ease Inc., Minneapolis, MN; 800-325-9829; 612-378-9449; fax, 612-378-2152 (continued)					
Design-Expert Version 4 $795 Circle No. 425	IBM 286 or better	MS-DOS, 2 MB of disk space, 640 kB of RAM, EMS utilized, mouse and math compressor supported	Response-surface methods used to optimize processes or mixtures	Stepwise regression; design evaluation	Locates peak of performance in process or formulation
Strawberry Tree, Sunnyvale, CA; 800-736-8810; 408-736-8800; fax, 408-736-1041					
WorkBench PC WorkBenchMac IBM PC: $995 Mac: $995 Circle No. 426	IBM PC: 386, 486 or compatible Mac: II, IIx, cx, xci, fx, si, vx, Centris 650, Quadra	[IBM PC] 1 MB of disk space, 640 kB of RAM; [Mac] floppy and hard disk drives, 2 MB of RAM	A control, data logging, and display software environment	Object-oriented data acquisition and management of measured data; allows user to display and log data, create control routines, or set alarms	No programming required
T.A.L. Enterprises, Philadelphia, PA; 800-722-6004; 215-763-2620; fax, 215-763-9711					
Software Wedge DOS: $129 Windows: $199 Windows Pro: $395 Circle No. 427	DOS: any IBM-compatible PC Windows: any PC with Windows or OS/2	[DOS] 2.0 or later, 270 kB of disk space, 512 kB of RAM; [Windows] 3.x, 500 kB of disk space, 1 MB of RAM	Adds serial I/O capabilities to any DOS, Windows, or OS/2 application; reads real-time data from any RS232 device/instrument; has full support for data parsing and filtering, date/time stamps, macro insertion, and more	New Pro version offers expanded features including additional data parsing, filtering, and formatting functions; can place a serial output "buffer" in any application; other powerful features	Supports up to 32 serial ports at one time; compatible with any RS232 instrument/device or PC application; fully guaranteed
Universal Technical System, Inc., Rockford, IL; 800-435-7887; fax, 815-963-8884					
TK Solver 2.0 Mac version 1.0: $395 IBM PC 2.0: $595 Circle No. 428	Mac, IBM PC, Unix, VAX/VMS	[IBM PC] DOS 2.0 or later, 3 MB of disk space, 1 MB of RAM; [Mac] System 6.X or later, 1.75 MB of disk space, 1.5 MB of RAM	Rule-based system can be used as an algebraic problem-solving tool, math model builder, and knowledge management system; provides an environment for engineers and scientists that solves forward and backward	Keystroke macros presentation view	Over 100 000 users

CGM=Computer Graphics Metafile; DDE=dynamic data exchange; EPS=Encapsulated PostScript; GPIB=general-purpose interface bus; GUI=graphical user-interface; HP=Hewlett-Packard workstations; HPGL=Hewlett-Packard Graphics Language; HP VEE=Hewlett-Packard Visual Engineering Environment ; IBM PC=IBM PCs and compatibles; LAN=local-area network; Mac=Macintosh; OLE=object linking and embedding (a Windows feature); PID=proportional-integral-derivative; PLC=programmable logic controller; Scada=supervisory control and data acquisition; SGI=Silicon Graphics Inc.; SQC=statistical quality control; SQL=standard (or structured) query language; Sun=Sun workstations; VI=virtual instruments; VXI= VMEbus Extensions for Instrumentation.

To probe further

SYMBOLIC MATH. For more information about MathSource, send an e-mail message containing the line "Help Intro" to the MathSource server at MathSource@wri.com. To obtain a full listing of all materials in MathSource, send an e-mail message containing the line "Find" to the same address.

Important sites for math software over the Internet include WUARCHIVE (USA) at wuarchive.wustl.edu. and GARBO (Finland) at garbo.uwasa.fi. These offer a large variety of programs, including many of interest to scientists and engineers.

A file on frequently asked questions (FAQs) on symbolic math programs and their vendors is available through a file transfer protocol from math.berkeley.edu in the directory: pub/Symbolic_Math. A file on FAQs on Matlab and related products is available from csi.jpl.nasa.gov [128.149.29.4] as /pub/matlab/FAQ.

A new list, specializing in electrostatics, has recently appeared on the Internet. To subscribe, send a message to p00366@-psilink.com. To join MathGroup, which serves 1500 Mathematica users, send an e-mail message to mathgroup-request@yoda.physics.unc.edu.

Access to statistics software and databases at Carnegie Mellon University, Pittsburgh, can be automatically obtained by sending the message "send index" to the e-mail address statlib@lib.stat.cmu.edu. A similar message to the address netlib@research.att.com will provide access to a math library compiled by researchers at AT&T Bell Laboratories, Murray Hill, NJ, and Oak Ridge National Laboratory/University of Tennessee in Knoxville.

DATA ANALYSIS AND VISUALIZATION. Several books and videotapes on visualization are available from the IEEE Computer Society Press, 10662 Los Vaqueros Circle, Box 3014, Los Alamitos, CA 90720-1264; 1-800-CS-BOOKS (United States only); fax, 714-821-4641. Two other books among several titles that are well worth checking out are *The visual display of quantitative information* by Edward R. Tufte (Graphics Press, Cheshire, CT, 1983) and *Visualizing data* by William S. Cleveland (Hobart Press, Box 1473, Summit, NJ 07902-8473).

DATA ACQUISITION. Data acquisition software will be among the topics discussed during the Instrumentation and Measurements Technology Conference, May 10–12 in Hamamatsu, Japan. Contact: Robert Meyers, Myers/ Smith, Inc., 3685 Motor Ave., Los Angeles, CA 90034-5750; 310-287-1463; fax, 310-287-1851.

In "Adapting laptops to data acquisition" [*IEEE Spectrum*, October 1993, pp. 45–47], Allen E. Tracht discusses how portable computers can be made to accept medium-speed data through their parallel port. ✦

ACKNOWLEDGMENTS

In preparing this special focus report, *IEEE Spectrum* called on many sources. We are specially indebted to the individuals listed below for their advice and guidance, although their identification with the report should not be construed as their endorsement of any opinions or products covered in these pages, nor of the accuracy of the statements made in the articles.

The advisers for this report were: John Hines, silicon sensors engineer with Honeywell Inc.'s MicroSwitch Division, Richardson, TX; Robert W. Robison, senior research engineer, Southwest Research Institute, San Antonio, TX; John L. Schmalzel, associate professor, division of engineering, University of Texas, San Antonio; Capers Jones, chairman, Software Productivity Research Institute, Burlington, MA; and Michael S.P. Lucas, professor, department of electrical engineering and computer science, Kansas State University, Manhattan.

EEs' tools & toys

Engineering calculators get graphical interface

It had to happen. With menu-driven software proliferating all over the world of computers, it was only a matter of time before graphical user-interfaces were incorporated into hand-held calculators as well. And they were in answer to the same need: as practitioners in all areas of our industry know all too well, endowing a device with advanced functionality is not the same as making that functionality readily accessible to the user.

The latest technical calculators from Hewlett-Packard Co., the 48G and the 48GX, which replace the 48S and 48SX, respectively, are above all notable for their ease of use. In addition to all the functionality of the HP 48 series, both offer dialog boxes and fill-in-the-blank forms. As a result, a new user can get a lot done on the calculators without reading the manuals.

The new calculators differ from each other in only three ways: RAM, expandability, and price. The 48GX has 128 kB of RAM, expansion slots for up to 4 MB of additional memory, and a price of $350; the 48G has 32 kB of RAM, no expansion slots, and a $165 price. Both are faster than their predecessors and feature such enhancements as three-dimensional plots and built-in calculus and graphics functions for finding roots, intersections, local extremes, derivatives, slopes, and areas under curves.

The calculators include more than 200 built-in scientific and engineering equations that cover a wide variety of applications in electrical engineering, chemistry, and geometry. All the equations can use the HP Solve feature for thorough analysis. Many are accompanied by pictures that illustrate the application to which the equation pertains [photo].

The HP 48G and 48GX calculators have over 200 built-in equations for solving problems in electrical engineering, chemistry, and geometry. Many of them, like the equation for the inductance of a toroidal choke, are accompanied by illustrations [shown] that clarify the meaning of their various parameters.

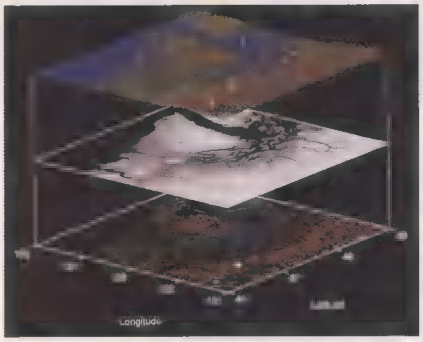
An upgrade plan is available for current owners of HP 48 family calculators. *Contact: Inquiries Manager, Hewlett-Packard Co., 1000 N.E. Circle Blvd., Corvallis, OR 97330; 503-752-7736; or* **circle 120.**

SOFTWARE

Desktop image processing

As image processing becomes an ever more important enabling technology for many applications, the need increases for two distinct, but related, kinds of software: routines for processing and rendering images, and tools for developing algorithms for creating those routines. Of course, it helps to combine

the two, which is what The MathWorks has done with an extension of its popular Matlab technical computing environment called the Image Processing Toolbox.



This Image Processing Toolbox output shows altitude data for the Puget Sound region of the United States and Canada rendered as a textured-mapped surface [top], a gray-scale image [center], and a contour plot [bottom].

The Toolbox itself includes many routines capable of analyzing, filtering, and enhancing just about any image—whether scanned in from a photograph or acquired from a sensor array. Matlab, on which it is based, is well suited to image processing, since its language is optimized for manipulating matrices (the software's name is an abbreviation for "matrix laboratory").

To ensure maximum accuracy in executing both built-in and user-written algorithms, the Toolbox exploits its host computer's floating-point hardware. As a result, it is far more accurate than image-processing programs that treat image data as 1-byte integers.

The Matlab Image Processing Toolbox supports all leading image formats, including TIFF, GIF, and HDL, as well as platform-specific formats like PCX, Windows BMP, XWD, and PICT. Pricing begins at $895 for single-user copies for MS-Windows PCs. It is available in versions for the Apple Macintosh, and for Sun, Hewlett-Packard, DEC, IBM, and Silicon Graphics Unix workstations. *Contact: The MathWorks Inc., 24 Prime Park Way, Natick, MA 01760; 508-653-1415; fax, 508-653-2997; or* **circle 121.**

EDUCATION

Affordable build-your-own robot

Intended mainly for educators, industrial modelers, and hobbyists, the Robix RCS-6 robotic construction system from Advanced Design Inc. (ADI) is a kit of basic hardware and software components that just about anyone with an IBM-type PC can use to design, build, and operate a variety of coordinated-motion desktop robots. The kit contains six servo motors, an interface board with eight analog and seven digital inputs, control-panel software, tools, safety goggles, an instruction manual and video, and an assortment of machined aluminum and plastic structural pieces.

Learning to work with the Robix RCS-6 should be easy. According to ADI, it takes just 15 minutes to build a six-motor assembly arm that can put a marble on a golf tee with smooth, velocity-ramped motions.

Users are not obliged to run their robots with the ADI-supplied control-panel software. Instead they can write their own routines in C or Microsoft QB 4.5. They may also add their own sensors and other hardware to create robots that respond to external stimuli. For users who find it inconvenient to buy sensors on their own, the components are available from ADI.

Robix RCS-6 sells for $550. It requires a DOS-type PC with 450 kB of free RAM, a parallel port, and a standard parallel-port cable. *Contact: Advanced Design Inc., 1101 East Rudasill Rd., Tucson, AZ 85718; 602-544-2390; fax, 602-575-0703; or* **circle 122.**

COORDINATOR: Michael J. Riezenman
CONSULTANT: Paul A.T. Wolfgang, Boeing Defense & Space Group

Calendar

(Continued from p. 7)

Department of Electrical Engineering, Queen's University, Kingston, ON, K7L 3N6, Canada; 613-545-6564; fax, 613-545-6866.

DECEMBER

Fifth Symposium on Parallel and Distributed Processing (C, DS/CS Chapter); Dec. 1–4; Omni Mandalay Hotel, Irving, TX; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013.

International Conference on Building and Sharing of Very Large-Scale Knowledge Bases (C); Dec. 1–4; Keio Plaza Hotel, Tokyo; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

International Electron Devices Meeting (ED); Dec. 5–8; Washington Hilton Hotel, Washington, DC; Melissa Widerkehr, IEDM, 1545 18th St., N.W., Suite 610, Washington, DC 20036; 202-986-1137; fax, 202-986-1139.

International Symposium on Nonlinear Theory and its Applications—NOLTA '93 (CAS, NN et al.); Dec. 5–9; Sheraton Waikiki Hotel, Honolulu, HI; Mamoru Tanaka, Department of Electrical and Electronics Engineering, Sophia University, Kioicho 7-1, Chiyoda-ku, Tokyo 102, Japan; (81+3) 3238 3878; fax, (81+3) 3238 3321.

Seventh International Workshop on Software Specification and Design (C); Dec. 6–7; Holiday Inn Crowne Plaza, Redondo Beach, CA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Ninth Annual Computer Security Applications Conference (C); Dec. 6–10; Orlando Marriott, Orlando, FL; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W. , Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Semiconductor Interface Specialists Conference (ED); Dec. 9–12; Bonaventure Resort and Spa, Fort Lauderdale, FL; Lalita Manchanda, AT&T Bell Laboratories, Crawfords Corner Road, M/S 4C 406, Holmdel, NJ 07733; 908-949-1679; fax, 908-949-9017.

Winter Simulation Conference—WSC '93 (C, SIMC); Dec. 12–15; Los Angeles Biltmore Hotel, Los Angeles; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

Workshop on Automatic Speech Recognition (SP); Dec. 12–15; Snowbird Conference Center, Snowbird, UT; Esther Levin, AT&T Bell Laboratories, 600 Mountain Ave., 2C-574, Murray Hill, NJ 07974; 908-582-2788; or Roberto Pieraccini; 908-582-3558.

Seventh IEE European Conference on Mobile and Personal Communications (UKRI Section); Dec. 13–15; Brighton Centre, United Kingdom; Louise Bousfield, IEE Conference Services, Savoy Place, London WC2R OBL, United Kingdom; (44+71) 344 5467; fax, (44+71) 497 3633.

International Conference on Microelectronics (ED); Dec. 14–16; King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia; M.I. Elmasry, VLSI Research Group, ECE Department, University of Waterloo, Waterloo, ON N2L 3G1, Canada; 519-885-1211, ext. 3753; fax, 519-746-5195.

International Symposium on Algorithms and Computation—Isaac '93 (C); Dec. 15–17; City Polytechnic of Hong Kong, Kowloon; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903; 202-371-1013; fax, 202-728-0884.

32nd Conference on Decision and Control (CS); Dec. 15–17; Marriott Rivercenter Hotel, San Antonio, TX; Ching-Fang Lin, American GNC Corp., 9131 Mason Ave., Chatsworth, CA 91311; 818-407-0092; fax, 818-407-0093.

Workshop on Computer Architecture for Machine Perception—Camp '93 (C, CAS); Dec. 15–17; New Orleans Riverside Hilton, LA; Magdy A. Bayoumi, Center for the Advancement of Computer Studies, University of Southwestern Louisiana, Lafayette, LA 70504-4330; 318-231-6853; fax, 318-231-5791; or Larry Davis, Umiacs, University of Maryland, College Park, MD 20742; 301-405-6722.

Fourth International Symposium on Recent Advances in Microwave Technology—Isramt '93 (MTT et al.); Dec. 15–18; New Delhi/Agra (Taj Mahal City), India; Banmali Rawat, Department of Electrical Engineering, University of Nevada, Reno, NV 89557-0153; 702-784-6927; fax, 702-784-6627; or Bharathi Bhat, Care, Indian Institute of Technology, Hauz Khas, New Delhi 110016, India; (91+11) 665 674; telex, 3173087 I.I.T. IN.

JANUARY

27th Hawaii International Conference on Systems Sciences—HICSS-27 (C); Jan. 4–7; Maui InterContinental Resort, Maui, HI; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Seventh SEI Conference on Software Engineering Education(C); Jan. 5–7; St. Anthony Hotel, San Antonio, TX; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Annual Reliability and Maintainability Symposium—RAMS (R); Jan. 25–27; Anaheim Marriott Hotel, Anaheim, CA; V. R. Monshaw, Consulting Services, 1768 Lark Lane, Cherry Hill, NJ 08003; 609-428-2342.

Power Engineering Society Winter Meeting (PE); Jan. 30–Feb. 3; New York Hilton & Towers, New York; Frank E. Schink, 14 Middlebury Lane, Cranford, NJ 07016-1622; 908-276-8847.

FEBRUARY

Tenth Semiconductor Thermal Measurement and Management Symposium—SEMI-THERM (CHMT); Feb. 1–3; Red Lion Hotel, San Jose, CA; Bonnie Crystall, C/S Communications, Inc., Box 23899, Tempe, AZ 85285; 602-625-0700.

15th Annual Aerospace Applications Conference (AES); Feb. 5–12; Mountain Haus, Vail, CO; Chuck Zamites, 1719 Morgan Lane, Redondo Beach, CA 90278.

Basque International Workshop on Information Technology (C); Feb. 7–9; Hotel Athlanthal, Biarritz, France; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Second CAD-Based Vision Workshop (C); Feb. 8–10; Seven Springs Mountain Resort, Champion, PA; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

Applied Power Electronics Conference and Exposition—APEC '94 (IA, PEL); Feb. 13–17; Walt Disney World Resort, Orlando, FL; Pamela Wagner, Courtesy Associates, 655 15th St., S.W., Suite 300, Washington, DC 20005; 202-639-4990; fax, 202-347-8109.

Tenth International Conference on Data Engineering (C); Feb. 14–18; Doubletree Hotel, Houston, TX; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1992; 202-371-1013; fax, 202-728-0884.

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Air Force Office of Scientific Research

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Southeastern Center For Electrical Engineering Education

THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFOSR) OFFERS FELLOWSHIPS FOR GRADUATE STUDIES LEADING TO DOCTORAL DEGREES IN SELECTED SCIENCE AND ENGINEERING DISCIPLINES

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ELIGIBILITY: Applicants must be U.S. citizens with baccalaureate degree by September 1994. Eligibility is further restricted to individuals who have not attended graduate school in science or engineering since receiving their baccalaureate degree. All qualified applicants will receive consideration without regard to age, color, race, religion, sex or national origin.

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CHAIRPERSON
Electrical Engineering
University at Stony Brook

The College of Engineering and Applied Sciences at SUNY Stony Brook has reopened its search for chairperson of the Department of Electrical Engineering, effective for the 1994 Fall Semester or sooner.

The University has selected Electrical Engineering as an area for special emphasis and development. Substantial resources will be made available to the new Chair for this purpose.

Candidates are expected to have established a clear record of excellence in scholarship and research as demonstrated by publication history and status within the discipline. Of special importance will be leadership qualities, willingness and ability to work closely with a diverse community of scholars and administrators in the College and in industry.

The Department, one of six in the College of Engineering and Applied Sciences, has 20 full time faculty. An additional 5 faculty members have joint appointments with other departments. Five of the faculty are Fellows of IEEE.

The Department offers B.E., M.S., and Ph.D. degrees. There are currently 320 undergraduates enrolled in two ABET accredited programs - Electrical Engineering and Computer Engineering. Graduate enrollment includes about 100 full-time students. Faculty research interests are in: Bioengineering, Computer-Aided Design, Communication Systems and Networks, Computer Architecture, Control Systems, Fault-Tolerant Computing, Machine Vision, Microwave Electronics, Optoelectronics, Signal Processing, and Analog/Digital VLSI.

Located on Long Island's beautiful north shore, SUNY Stony Brook, now in its thirty-sixth year, is a major research university in the State of New York. Campus student enrollment is 17,233 and there are 1,533 faculty members. The College of Engineering and Applied Sciences is one of five major academic units which altogether offer graduate degrees in more than 43 subject areas.

Applications (with vita and 3 references) and nominations should be addressed to : *Stephen S. Rappaport, Leading Professor; Chair, Electrical Engineering Search Committee; Department of Electrical Engineering; SUNY Stony Brook; Stony Brook, N.Y. 11794-2350.*

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University of Waikato

Te Whare Wānanga o Waikato

Hamilton, New Zealand

PROFESSOR OF COMPUTER SCIENCE OR INFORMATION SYSTEMS

The University is seeking to appoint a second Professor in the Department of Computer Science. The appointee will join the existing Professor, Ian Witten, and will be expected to fill the position of Chairperson of Department for at least three years after appointment.

The department's principal teaching contributions are to the Bachelor of Computing and Mathematical Sciences and the Computer Science and Information Systems Programmes in the Bachelor of Science and Bachelor of Social Science degrees. It also plays an important service role in the Bachelor of Management Studies and other degrees by teaching introductory computing. The principal research areas in the department are machine learning, user interfaces, computer music and parallel computation.

Applicants should hold a doctoral degree and have a substantial research record and experience of postgraduate supervision. The successful applicant will have broad interests and experience in computer science and information systems and should have demonstrated leadership in the areas of teaching, curriculum development and academic administration.

The department has an establishment of about thirty academic and support staff and with 400 full time equivalent students is one of the largest departments in the University. Its staff teach and conduct research in both computer science and information systems. Forty students are currently enrolled at masters and doctoral level in the department. As well as large network PC and Mackintosh teaching laboratories, departmental resources include SUN workstations, NeXTs, hardware and communications laboratories, a variety of uni- and multi-processor Unix servers and access to the University's VAX cluster. The Internet is used extensively by staff and students.

The current salary range for Professors is NZ$80,080 to NZ$99,840 per annum.

Enquiries of an academic nature may be made to Professor Ian Graham, Dean of the School of Computing and Mathematical Sciences, (email ian@waikato.ac.nz, tel. (64 7) 838 4136, fax (64 7) 838 4155). Information on the method of application and conditions of appointment can be obtained from Personnel, Academic Staffing, The University of Waikato, Private Bag 3105, Hamilton, New Zealand (email rgtywp4@waikato.ac.nz; tel. (64 7) 856 2889; fax (64 7) 856 0135). Application quoting reference number A93/46 should reach Academic Staffing by **30 November 1993.**

Places for appointees' children may be available in the creche run by the Campus Creche Society (Inc).

Equal opportunity is University policy.

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SCIENTIFIC POSITION

The Department of Advanced Technology at Brookhaven National Laboratory has a position available for an individual with a doctorate in electrical engineering or computer science, with experience in the field of pattern recognition.

The successful candidate will join a research program involved in building a mobile Raman chemical sensor for field test of the physical principle, and will have the task of developing a pattern recognition program for chemical identification of unknown chemical mixtures by Raman spectral fingerprint. Knowledge of neural network architecture for microprocessors; capability to write software to train and test these architectures on real data; experience in digital (including nonlinear adaptive) signal processing; proficiency in C, C++, UNIX shell and Assembly languages, and the ability to obtain and hold "Q" access authorization from the U.S. Department of Energy (the government agency from which Brookhaven derives its majority funding) are essential.

Applicants should submit a curriculum vitae and the names of three references to: Dr. Carl L. Chen or Dr. Joseph P. Indusi, Department of Advanced Technology, Building 197C, Brookhaven National Laboratory, Associated Universities, Inc., P. O. Box 5000, Upton, Long Island, NY 11973-5000. Equal Opportunity Employer M/F/D/V.

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Manager of CAD and Design Methodology — Create ■ global CAD effort in support of developing mixed signal ICs, including RF analog and digital circuits. Proven record in IC design, characterization and simulation methodologies.

MMIC Power Designer — Develop integrated RF power amplifiers to service the personal communications market. Experience in bipolar and GaAs technologies needed.

Senior Systems Engineer — Develop ICs to service the personal communications market, will work closely with customers, marketing and IC designers to define new products. Must have experience in modulation/demodulation techniques, high frequency filtering and/or system level simulation.

Senior Engineer/Project Manager — Develop material and packages for improved product performance and cost of linear hybrids. Statistical analysis tools will be utilized in evaluation of technical approaches which must include interface to manufacturing processes.

ADVANCED PACKAGING DEVELOPMENT CENTER

Sr. Mechanical Engineer — Develop thermal and mechanical technologies in support of new product development for portable products. Requires thorough knowledge of thermal engineering, engineering, mechanics, design and Finite Element Method, as well as ■ good understanding of mechanical behavior of materials and experimental techniques in thermal and stress field.

Digital/Mixed Signal Designer — Develop electrical technologies and design rules in support of low power/low voltage digital packages for portable applications. Experience in digital and/or mixed signal electronics should include thorough knowledge of chip design issues, driver/receiver design and test chip/structure design.

HYBRID POWER MODULES

Device Physics Technologist — Model and develop dense/sense/IGBTs, fast diodes with high voltage and soft recovery characterization of hybrid power modules. Extensive knowledge of circuits, design of experiments and SPICE modeling required.

Materials Technologist — Responsible for material package development for hybrid power modules. Must be expert in interaction of different materials (mechanical/electrical) and able to FMEA and analyze failures.

POWER PRODUCTS DIVISION

Senior Device Scientist — Work on a design team responsible for new power product development. Requires advanced technical expertise in power devices, design wafer process integration, packaging and testing. Hands-on experience with modeling tools for process device and circuit simulation essential.

Senior Applications Engineer — Requires experience in the design of power electronic circuits such as Modern Power MOS, IGBT, MCT, GTO and fast switching rectifiers. Knowledge of regulatory requirements of power circuits, four layer bipolar devices a plus.

Senior Device Designer — IGBT and Power FETS — Responsible for device design/development of discrete power semiconductors and power ICs. Experience developing high voltage devices a must, as is knowledge of such tools as PISCES, SUPREME and SPICE.

CREATE THE CORE

Senior Applications Engineer — Direct customer involvement during product definition phase. Will also apply new devices to determine customer value. Must be expert in design of power converters, UPS, DC-DC converters and motor controls. Must know technical trade-offs between different technologies and impact on circuit design, as well as computer based circuit simulation (SPICE, SABER).

Senior Device Engineer — Bipolar Power — Determine wafer probe yield enhancement opportunities and improvement in final test yields. Expertise in statistical experimental design probe and package test and physical failure analysis methods needed.

GROUP QUALITY ASSURANCE

Sr. Staff Scientist — Seek ■ strong problem-solver with good communication skills to establish organic analysis capabilities. Develop methods for characterization of mold compounds, die coat, adhesives, fluxes, contaminants, solvent and polymer gels, and work with new product development personnel and process engineers to correlate characterization properties with performance.

Metallurgist — Develop/lead analytical support of the metallurgical lab, entailing encapsulated/non-encapsulated cross sectioning of semiconductors and associated packaging. Requires a self-motivated, team-oriented individual with a thorough understanding of metallography, microstructures and semiconductor fabrication.

SIGNAL PRODUCTS DIVISION

Circuit Designer/Application Manager — Act as Technologist and Group Leader of Circuit Design and Technology Center. Experience in linear circuit design and use of circuit modeling tools needed; background as Technology Manager desirable.

Technology Director, Chemical Sensor Business Unit — Evaluate currently available sensor technologies for suitability to meet business plan requirements. Working knowledge of silicon based semiconductor process needed.

GROUP MANUFACTURING

Materials Technologist — Involves process/product improvement focused on developing applications of leadframe ceramics, plastics, etc. Also work in new product development and new material applications.

Thermal Stress Finite Element Analysis Technologist — Develop/lead team of modeling experts providing tools for material analysis and DFM to new product introduction. Set standards/practices of validating models and selecting modeling tools.

Computer Integrated Manufacturing Technologist — Define/implement CIM platform using technology and standards. Develop CIM expertise to assure appropriate configurations of manufacturing equipment and application of CIM technology.

Robotics and Flexible Manufacturing Technologist — Provide technological direction and develop semiconductor final manufacturing applications. Will coordinate with international staff, establish future manufacturing technology, and develop standards/practices for implementing robotics flexible manufacturing driven by computer vision techniques.

Shaping & Polishing Scientist — You'll be ■ key contributor to the development and implementation of 150mm and 200mm processes to meet or exceed current parametrics, and develop "next generation" parametrics to help capability lead demand. Strong leadership and team skills important.

Interested candidates are invited to mail resumes to: **Dennis Deakin, Motorola SPS Sourcing, Dept. SPS-509, 1438 W. Broadway, Suite B-100, Tempe, AZ 85282.** An Equal Opportunity/Affirmative Action Employer.

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Semiconductor Products Sector

Washington watch

(Continued from p. 10HT)

Hi-tech help for U.S. firms

Another program that appears to be gaining momentum is the Advanced Technology Program (ATP), run by the National Institute of Standards and Technology (NIST) in Gaithersburg, MD. Starting out as a pilot project in 1990 with $10 million in funding to aid U.S. competitiveness, ATP today has funding of $68 million, and under the Clinton administration's plans is expected to have funding of $750 million by 1997.

To counter any hint of "technology pork," the program is driven largely by industry. The new NIST director, Arati Prabhakar, wants the ATP to gain as much leverage as possible by focusing on specific technology areas. These are yet to be determined, but an example would be intelligent manufacturing.

Prabhakar, who was to discuss the program's upscaling with industry on Oct. 19, told *IEEE Spectrum* that five-year grants will be awarded annually to the tune of $20 million to $50 million (to be matched by contractors). Selection will be based on projected economic impact, technological soundness, the breadth and depth of participants' strengths, and whether government dollars can make a real difference, among other criteria. For more information, contact NIST public affairs at 301-975-2000.

Federal labs seek business

The Federal government is downright anxious to help commercialize technologies from its hundreds of laboratories. How to accomplish this varies with the lab. For instance, an agreement with NIST is much easier to make than one with a Department of Energy laboratory, because of decentralized control. According to a recent IEEE-U.S. Activities conference here on commercialization of technology, however, the rules are changing. Some in industry are now finding it easier to work with Federal laboratories than with universities, which have intellectual property constraints.

How may an engineer begin to take advantage of these opportunities? One way is through the National Technology Transfer Center, Wheeling, WV, recently created by Congress. Its free technical request service became available last October and has received about 2500 requests from nearly 1500 individuals, most of whom work at small companies. The toll-free number is 800-678-NTTC. A complimentary guide to accessing a free electronic bulletin board is also available.

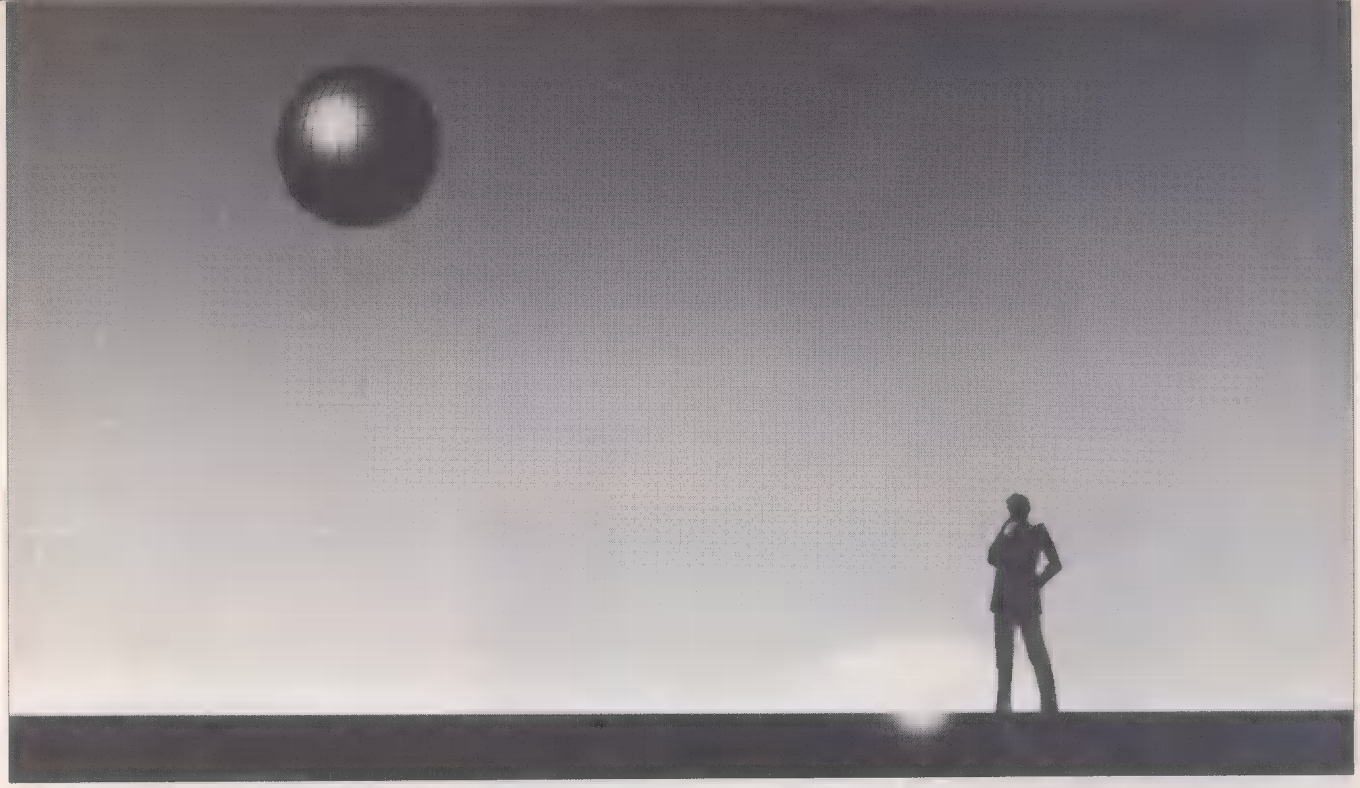
Former foes collaborate

The two principal Cold War adversaries held their first meeting on high-technology partnerships in September, with Vice President Al Gore and Russian Prime Minister Viktor Chernomyrdin (now the Russian Vice President) presiding. The two countries agreed to cooperate on space science and exploration, earth environmental monitoring, and fundamental aeronautical sciences. Both parties were "convinced that a unified Space Station can offer significant advantages," according to a White House statement.

In another collaboration, members of the IEEE Computer Society were invited to attend a soirée at the Russian embassy in recognition of their work in creating technical information libraries in Eastern Europe. Details on U.S.-Russian endeavors were to be presented in reports due Nov. 1.

Info infrastructure a priority

With most attention focused on health care and the North American Free Trade Agreement (Nafta), Vice President Gore called a press conference in mid-September to release a 26-page "agenda for action" on the national information infrastructure. "No one should doubt how important this is to the



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Explore various leading edge alternatives through technology prototyping in mobile telecommunications and related support systems. Requires a broad comprehension of telecommunications technology, OOD, reliable computing, distributed processing elements and RTOS concepts. Background in modern software architectures, standard APIs, wireless communications and telephony required.

Operations, Administration & Maintenance (OA & M) System Engineers

Positions are available in: ▪ Data Communications (TCP/IP, X.25, Routers, LAN/WAN, Ethernet, CMISE, SNMP, SUN) ▪ Wireless Switching (GSM, USDC, AMPS, Performance, Fault and Traffic Management, Billing, AMA) • Customer Interface (Provisioning, Trouble Ticket, X-Windows GUI, Relational Database) • GSM Base Station Systems.

Network Systems Engineers

Requires system/network expertise in call processing area of a telecommunications system development. Must have detailed understanding of methodology used to perform functional partitioning of call processing functions as well as required signaling and protocols.

Paging System Engineers

The candidates selected will define functional, performance and interface requirements for the paging infrastructure subsystem of the **IRIDIUM™/SM** Gateway Segment, as well as define hardware and software architecture. Knowledge of paging systems architectures, services, infrastructure equipment, protocols and software is highly desirable (strong preference for ERMES and Telocator).

OTHER CHALLENGING OPPORTUNITIES

IC Design Engineer

Will act as integrated circuit design task leader for high speed GaAs development. Experience with encryption products and project leader experience a plus.

Software Engineers

Intermediate and senior-level positions available requiring proficiency in "C" and Ada. Knowledge of OOA/OOD desirable. For senior assignments, project leadership and planning experience also desired.

Systems Engineers

Supporting users of the Signal Processing Worksystem (SPW), will coordinate user group activities and serve as the primary interface with CADENCE on a broad range of SPW-related topics. SPW expertise is essential.

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Government and Systems Technology Group

Washington watch

Administration," he said, calling it critical to the country's economic future. Industry is already investing about $50 billion a year in the infrastructure.

The Government's role is to accelerate some developments and address such issues like intellectual property rights and privacy. For a copy of the agenda, contact: NTIA NII Office, 15th Street and Constitution Avenue, Washington, DC 20230; 202-482-1840; fax, 202-482-1635; Internet; nii@ntia.doc.gov.

Streamlining Government

A week before the information infrastructure briefing, Gore released the 168-page report, "Creating a Government that Works Better & Costs Less," based on a six-month review of how various sectors of the government operate nationally. The report contains more than 100 recommendations calling for changes, grouped according to such themes as fostering competitiveness and commercial practices, employing "guiding principles" rather than rigid rules, and decentralizing authority and accountability. The changes will bring about improvements affecting not only government services, but also procedures for Federal procurement, which amounted to more than $200 billion in 1992.

Applauding the report was a coalition of eight industry and trade groups, including the American Electronics Association, the Aerospace Industries Association, and the Electronic Industries Association. Highly readable, the report is sprinkled throughout with such aphorisms as "We can lick gravity, but sometimes the paperwork is overwhelming" (space pioneer Wernher von Braun) and "Were we directed from Washington when to sow and when to reap, we should soon want for bread" (Thomas Jefferson). Copies are available for $14 from the Superintendent of Documents, Box 371954, Pittsburgh, PA 15250; fax: 202-512-2250.

National medalists

Five IEEE members were among the 17 engineers and scientists honored by the White House in September with National Medals of Science and Technology. The honorees were Alfred F. Cho (F), AT&T Bell Laboratories, for molecular-beam epitaxy; Amos E. Joel Jr. (F), AT&T Bell Laboratories for telecommunications switching; William H. Joyce (M), Union Carbide Corp., for processing of plastics; Kenneth Olsen (LF), founder of Digital Equipment Corp., for computing technology; and technology transfer pioneer George Kozmetsky (A), founder of the IC2 Institute.

John A. Adam, Washington Editor

Recent books

The Corporate Cabling Guide. *McElroy, Mark W.*, Artech House, Norwood, MA, 1993, 111 pp., $60.

Pexlib Reference Manual. Ed. *Gaskins, Tom*, O'Reilly & Associates, Sebastopol, CA, 1992, 577 pp., $39.95.

The Computer Professional's Guide to Effective Communication. *Simon, Alan R.*, and *Simon, Jordan S.*, McGraw-Hill, New York, 1993, 275 pp., $29.95 (hardcover), $19.95 (paperback).

Underwater Acoustic Modeling: Principles, Techniques and Applications. *Etter, Paul C.*, Elsevier Science Publishing, New York, 1992, 304 pp., $120.

The New Shop Floor Management: Empowering People for Continuous Improvement. *Suzaki, Kiyoshi*, Free Press, New York, 1993, 256 pp., $29.95.

Numerical Recipes in Fortran: The Art of Scientific Computing, 2nd edition. *Press, William H., et al.*, Cambridge University Press, New York, 1992, 963 pp., $49.95.

Digital Design Fundamentals. *Breeding, Kenneth J.*, Prentice Hall, Englewood Cliffs, NJ, 1992, 446 pp., $60.

Implementing Client/Server Computing: A Strategic Perspective. *Boar, Bernard H.*, McGraw-Hill, New York, 1993, 233 pp., $39.95.

Internetworking with TCP/IP: Client-Server Programming and Applications. *Comer, Douglas E.*, and *Stevens, David L.*, Prentice Hall, Englewood Cliffs, NJ, 1993, 498 pp., $50.

Telecommunications Local Networks. *Ritchie, W.K.*, and *Stern, J.R.*, Chapman & Hall, New York, 1993, 321 pp., $99.

McGraw-Hill Data Communications Dictionary. *Potts, William F.*, McGraw-Hill, New York, 1993, 268 pp., $34.95.

Exploring Chaos: A Guide to the New Science of Disorder. Ed. *Hall, Nina*, W.W. Norton & Co., New York, 1993, 223 pp., $25.

Performance Contracting for Energy and Environmental Systems. *Hansen, Shirley J.*, Prentice Hall, Englewood Cliffs, NJ, 1993, 317 pp., $69.

Uninterruptible Power Supplies. Eds. *Platts, John*, and *St. Aubyn, John*, IEE/Peter Peregrinus, Piscataway, NJ, 1992, 150 pp., $65.

Future Telecommunications: Information Applications, Services, & Infrastructure. *Heldman, Robert K.*, McGraw-Hill, New York, 1993, 234 pp., $29.95.

Software Quality Management. *Brinkworth, John W.O.*, Prentice Hall, Englewood Cliffs, NJ, 1992, 198 pp., $39.

The Navstar Global Positioning System. *Logsdon, Tom*, Van Nostrand Reinhold, New York, 1992, 256 pp., $44.95.

Looking Ahead: Human Factors Challenges in a Changing World. *Nickerson, Raymond S.*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1992, 450 pp., $89.95 (hardcover), $29.95 (paperback).

VAX C Programmer's Guide. *Shah, Jay*, McGraw-Hill, New York, 1993, 520 pp., $40.

Microelectronics Manufacturing Diagnostics Handbook. Ed. *Landzberg, A. H.*, Van Nostrand Reinhold, New York, 1993, 633 pp., $89.95.

Fortran 90 Handbook: Complete ANSI/ISO Reference. *Adams, J. C., et al.*, McGraw-Hill, New York, 1992, 740 pp., $79.95.

Recent books

Running Visual Basic for Windows. *Nelson, Ross*, Microsoft Press, New York, 1993, 285 pp., $22.95.

Computer Organization and the MC68000. *Livadas, Panos E.*, and *Ward, Christopher*, Prentice Hall, Englewood Cliffs, NJ, 1993, 698 pp., $61.33.

VSE/ESA: Performance Management and Fine Tuning. *Merrow, Bill*, McGraw-Hill, New York, 1993, 385 pp., $45.

Case*Method Function and Process Modelling. *Barker, Richard*, and *Longman, Cliff*, Addison-Wesley, Reading, MA, 1992, 386 pp., $54.95.

A Guide to Field Computing. *Blankenhorn, Dana*, New Riders/Prentice Hall, Carmel, IN, 1992, 656 pp., $29.95.

Microsoft Word for the Macintosh Step by Step. *Microsoft Corp.*, Microsoft Press, Redmond, WA, 1993, 272 pp., $29.95.

Token Ring Networks. *Nilausen, Jesper*, Prentice Hall, Englewood Cliffs, NJ, 1992, 196 pp., $35.

Computer Wars: How the West Can Win in a Post-IBM World. *Ferguson, Charles H.*, and *Morris, Charles R.*, Random House, New York, 1993, 272 pp., $23.

Mobile Communications Design Fundamentals, 2nd edition. *Lee, William C.Y.*, John Wiley & Sons, New York, 1993, 372 pp., $59.95.

Technology Edge: A Guide to CD-ROM. *Parker, Dana*, and *Starrett, Bob*, New Riders/Prentice Hall, Carmel, IN, 1992, 426 pp., $29.95.

Methods for Electromagnetic Field Analysis. *Lindell, Ismo V.*, Oxford University Press, New York, 1992, 290 pp., $83.

Inside Windows for Workgroups. *Boyce, Jim*, New Riders/Prentice Hall, Carmel, IN, 1992, 735 pp., $34.95.

How to Prepare, Stage, and Deliver Winning Presentations: New and Updated Edition. *Leech, Thomas*, Amacom, New York, 1993, 334 pp., $27.95.

Complete Guide to Microsoft Excel Macros, 2nd edition. *Kinata, Chris*, and *Kyd, Charles W.*, Microsoft Press, Redmond, WA, 1993, 490 pp., $29.95.

Que's Speed Up Your Computer Book. *Reed, Davie*, and *Nance, Barry*, Que/Prentice Hall, Carmel, IN, 1992, 395 pp., $29.95.

Op-Amps and Linear Integrated Circuits, 3rd edition. *Gayakwad, Ramakant A.*, Regents/Prentice Hall, Englewood Cliffs, NJ, 1993, 640 pp., $39.95.

Motif Programming in the X Window System Environment. *Parrette, William A.*, McGraw-Hill, New York, 1993, 466 pp., $44.95 (hardcover), $34.95 (paperback).

Running Microsoft Works 3 for the PC, 2nd edition. *Rubin, Charles*, Microsoft Press, Redmond, WA, 1993, 400 pp., $24.95.

Rapid Electrical Estimating & Pricing, 5th edition. *Kolstad, C. Kenneth*, and *Kohnert, Gerald V.*, McGraw-Hill, New York, 1993, 425 pp., $63.

Using Formal Description Techniques: An Introduction to Estelle Lotos and SDL. Ed. *Turner, Kenneth J.*, John Wiley & Sons, New York, 1993, 431 pp., $64.95.

Energy Efficiency and Human Activity: Past Trends, Future Prospects. *Schipper, Lee, et al.*, Cambridge University Press, New York, 1992, 385 pp., $49.95.

CLASSIFIED EMPLOYMENT OPPORTUNITIES

The following listings of interest to IEEE members have been placed by educational, government, and industrial organizations as well as by individuals seeking positions. To respond, apply in writing to the address given or to the box number listed in care of *Spectrum* Magazine, Classified Employment Opportunities Department, 345 E. 47th St., New York, N.Y. 10017.

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Academic Positions Open

Virginia Tech, Faculty Positions in Electrical Engineering. The Bradley Department of Electrical Engineering of Virginia Polytechnic Institute and State University (Virginia Tech) invites applications for tenure track faculty positions at the Assistant Professor level. Needs are in the areas of (1) optoelectronic devices and materials with emphasis on thin film applications and fiber optics, (2) high frequency power semiconductor devices with emphasis on electronic materials, device design and fabrication, smart devices, and applications, and (3) intelligent, adaptive, and learning control along with sensor-based robot control. Applicants must have a doctorate in Electrical Engineering, be interested in undergraduate, and graduate teaching, and be willing to secure research sponsorship. Virginia Tech is Virginia's land grant university offering degrees through the Ph.D. Send complete resume with references and employment/citizenship status to: Prof. Gary S. Brown, Search Committee, Bradley Department of Electrical Engineering, Virginia Tech, Blacksburg, VA 24061-0111. Applications will be accepted until 15 December, 1993, or until suitable candidates are selected. Virginia Tech has a strong commitment to the principle of diversity and, in that spirit, seeks a broad spectrum of candidates including women, people of color, and people with disabilities. Individuals with disabilities desiring accommodation in the application process should notify Kathy Atkins, Electrical Engineering Department, at 703-231-4136 or TDD/PC - 1-800-828-1120 or Voice - 1-800-828-1140 by 15 December 1993.

Electrical Engineering: The Department of Electrical Engineering at Memphis State University is now accepting applications for a tenure-track faculty position at the Assistant Professor level. Preference may be given to applicants with appropriate industrial experience. Applicants with research specializations in computer engineering, biomedical engineering, communications, power or electro-optics are preferred. Candidates should be available for employment by January 12, 1994. Research experience and potential for securing funds for research will be important considerations in candidate selection. An earned doctorate in electrical engineering or related area is required. Interested applicants should send resumes to: Dr. Carl E. Halford, Department of Electrical Engineering, Memphis State University, Memphis, TN 38152. Closing date for applications is November 15, 1993, with initial screening to begin at that time. However if needed, applications will be reviewed until positions are filled. Equal opportunity, affirmative action employer. Successful candidates must meet Immigration Reform Act criteria.

Princeton University. The Department of Electrical Engineering invites applications for a tenure-track position at the Assistant Professor level. Candidates are sought in the area of Information Sciences and Systems: Control, Systems, Communications, and Signal and Image Processing. Applicants should have an earned Ph.D., demonstrated research ability and a strong interest in graduate and undergraduate teaching. Applications should include a detailed resume and the names of references. Submissions should be mailed to Prof. Stuart Schwartz, Chairman, Dept. of Electrical Engineering, Princeton University, Princeton, NJ 08544. Princeton University is an Equal Opportunity Employer/Affirmative Action Employer.

The Department of Electrical and Computer Engineering, The University of Texas at Austin, invites applications for tenure-track positions at the assistant professor level, particularly in the area of software engineering. Applicants must demonstrate exceptional teaching ability and research potential. Excellent English communication skills are required. Excellent English communication skills are required. Applicants, who do not hold a Ph.D., must be making satisfactory progress toward a Ph.D. or equivalent in electrical engineering, computer engineering or a related area, with a reasonable expectation of completion by August 31, 1994. Successful candidates are expected to pursue an active research program, perform both undergraduate and graduate teaching, and supervise graduate students. Priority will be given to applications received by February 1, 1994. Send letter of application, vita and a list of addresses for at least three references to the following address: Dr. Stephen A. Szygenda, Chairman, Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX 78712-1084. The University of Texas at Austin is an Equal Opportunity/Affirmative Action Employer.

The Department of Bioengineering at the University of Utah has openings for two tenure-track positions in the area of "Biobased Engineering." Candidates must have an earned doctorate and a strong physical science or engineering background, with a specific biological direction to their research. We are specifically seeking candidates with demonstrated expertise in one of the following three areas: 1) Micro/Nano Fabrication of Inorganic, Organic, and Biomolecular Materials: use of inorganic materials, compliant biomaterials, or composite inorganic/polymeric materials to fabricate microsensors and microactuators, and the application of these microsystems to problems in the life sciences. 2) Cellular Bioengineering: cytoskeletal biomechanics, mechanisms of cell attachment, locomotion, and bioenergetics. 3) Neural Plasticity and Control: information processing and plasticity in higher neural centers, neural network architectures, and adaptive and hierarchical control systems. Appointees will be expected to develop significant research programs, to assist in the development of new teaching laboratories, and to teach graduate classes in their areas of specialization. A complete CV, names of three references, and a brief career goals/objectives statement should be sent to Dr. R. Normann, Chair, Department of Bioengineering, 2480 MEB, University of Utah, Salt Lake City, UT 84112 (phone 801-581-8528, Fax 801-585-5361) by January 15, 1994, or until qualified applicants are identified. The University is an AA/EO employer, encourages applications from women and minorities, and provides reasonable accommodation to the known disabilities of applicants and employees.

Hankuk Aviation University, Korea: The Department of Avionics invites applications for a faculty position at the level of assistant/associate professor in avionics. Applicants should have a Ph.D. in Avionics or Electrical Engineering with research experience in avionic systems. A successful candidate will teach and develop courses in both undergraduate and graduate levels, conduct and promote research in avionics. The University is a member of Hanjin Group like the Korean Air Lines, and is supported for the research on aerospace and avionic engineering from the research funds provided by the Hanjin Group and Korean government. The Department offers both M.S. and Ph.D. degrees. Applications will be accepted until the position is filled. Qualified applicants are encouraged to contact Dr. Shin-Nam Hong, Chairman, Department of Avionics, Hankuk Aviation University, 200-1 Hwajon-dong, Koyang, Kyunggi-do, 411-791, Korea (TEL: 02-308-3114).

The Johns Hopkins University. The Department of Mechanical Engineering. The Department invites applications for a tenure-track faculty position. The Department is looking for an exceptional individual to teach and conduct research in the areas of robotics and mechantronics. Applicants should have expertise in one or more of the following areas: micromachines, microelectromechanical systems, mobile robots and walking machines, robots for medical applications, mechanics of manipulation, and control of electromechanical systems. Applicants should have strong backgrounds in analytical and experimental methods. A doctorate is required as well as demonstrated experience in research and the potential for significant contributions to the research and teaching programs of the department. Applicants should submit their resumes before January 15, 1994 to professor W.N. Sharpe, Jr., Department of Mechanical Engineering, The Johns Hopkins University, Baltimore, MD 21218. Hopkins is an equal opportunity, affirmative action employer.

Bioengineering Faculty Position - Georgia Institute of Technology and Emory University School of Medicine will appoint eight new tenure-track faculty in bioengineering over the next four years. This expansion is supported by the receipt of a Whitaker Foundation Biomedical Engineering Development Award, which focuses on tissue engineering. Areas of special interest include bioartificial organs, biomaterials, biosensors, cellular applications of micromachined devices, cellular imaging, cellular immunology, controlled release systems, cryopreservation, drug delivery, gene therapy, microbiomechanics, and stem cell propagation. Candidates should provide a complete curriculum vitae, a description of their research interests, and the names and addresses of at least three references. Applications should be sent to: Robert M. Nerem, School of Mechanical Engineering, code: IES-17, Georgia Institute of Technology, Atlanta, GA 30332-0405. Georgia Tech and Emory University are equal opportunity employers.

University of Toronto, Department of Electrical and Computer Engineering. The Department of Electrical Engineering invites applications for a tenure-stream Assistant Professor position in the area of microelectronics. The applicant is expected to have a strong interest in circuit design with an emphasis on high speed mixed analog/digital applications. The position involves both research and teaching at the undergraduate and graduate levels. Applicants must have a doctoral degree in Electrical Engineering, an outstanding academic record and effective teaching ability. The position is supported by Bell Northern Research/Northern Telecom Electronics with whom active interaction is expected. Additional research support may be available through the Natural Sciences and Engineering Research Council of Canada (NSERC) Research Partnership Program. Salary is commensurate with qualifications and experience. Applicants should send a curriculum vitae, a statement concerning teaching and research interests, and a list of three references before December 31, 1993 to Professor Safwat G. Zaky, Chair, Department of Electrical and Computer Engineering, University of Toronto, Toronto, Ontario M5S 1A4, Canada. The Appointment will be made as soon as possible after the closure date. In accordance with Canadian Immigration requirements, priority will be given to Canadian citizens and permanent residents of Canada. The University of Toronto is

committed to employment equity and encourages applications from women, visible minorities, aboriginal people and physically challenged persons.

Research Associate. Conduct an independent study of the nonlinear optical effects in organic crystalline semiconductor quantum wells and II-VI photorefractive materials. Characterize novel material systems and structures. Develop physical models and implement devices for optical-limiting, photonic switching, and optical signal processing applications. Req: Ph.D. in Electrical Engineering. Ability to conduct wave-mixing and nonlinear transmission experiments in bulk and epitaxial films. Ability to process/fabricate device, operate visible and IR laser systems and electro-optic instrumentation. Ability to characterize materials using absorption and photoluminescence spectroscopy, EDAX, SEM and EPR. Knowledge of II-VI materials. Sal: $692.30/wk; 40 hrs/wk; Job/Interview site: Los Angeles, CA. Send this ad and your resume to job #ET3839, P.O. Box 269065, Sacramento, CA 95826-9065.

The University of Iowa, Department of Electrical and Computer Engineering: Applications are invited for tenure track faculty positions at all ranks. Positions are available starting in Spring 1994 as well as Fall 1994. Candidates should have interest or research expertise in the disciplines of Electrical and Computer Engineering. Preference will be given to candidates in the areas of Computer Architecture and Systems or Computer Graphics and Visualization or High Speed Networks or VLSI or Wireless Computing (A); Image Processing or Neural Networks (B); and Photonics (C). An earned Ph.D. in Electrical and Computer Engineering or allied field is required. Faculty responsibilities include effective classroom teaching at the undergraduate and graduate levels, developing curricula and laboratories, supervising M.S. and Ph.D. student research, publishing journal articles, and developing and maintaining an externally funded research program. Interested candidates should submit a letter stating their areas of specialization, a current curriculum vita, and have three letters of reference sent to: Chair, Faculty Recruiting Committee, Department of Electrical and Computer Engineering, The University of Iowa, Iowa City, Iowa 52242. Applications will be reviewed starting November 15, 1993, and will be accepted until the positions are filled. Women and minorities under-represented in the engineering profession are especially encouraged to apply. The University of Iowa is an Equal Opportunity/Affirmative Action Employer.

Cornell University - Postdoctoral position in integrated optics. Background and experience in fabrication and processing of III-V photonic devices required. Interested applicants please send resume to Professor C.L. Tang, 326 Phillips Hall, Cornell University, Ithaca, NY 14853. US Citizenship or Permanent Residence required.

The Electrical and Computer Engineering Department at Illinois Institute of Technology has two faculty position openings: i) a tenure-track Assistant or Associate Professor, preferably in the area of digital signal processing, and ii) a Chaired Professorship in the area of communications. Send resume to Prof. T. Wong, Chair, Faculty Search Committee, Department of Electrical and Computer Engineering, ITT, Chicago, IL 60616. IIT is an equal opportunity/affirmative action employer.

Chairperson, Department of Electrical and Computer Engineering, Marquette University. Nominations and applications are invited for the Chair of the Department of Electrical and Computer Engineering to start August 16, 1994. a leading Jesuit university, Marquette University derives a distinctive character from the combination of its religious commitments, its location in a major city, its excellent faculty with diverse religious convictions, and its deep involvement in and dedication to undergraduate and graduate education and scholarly research. Of the 12,000 students at Marquette, 400 are undergraduate students and 180 are graduate students in the Electrical and Computer Engineering Department. The Department is housed in newly renovated facilities on an attractive campus in a vibrant city with supportive industries. The Department has 17 faculty with an annual budget of externally supported research totaling about $1M. Faculty participate in the several interdisciplinary College of Engineering Research Centers. Candidates for the position should have a doctorate, a superior record of research and professional activities, and teaching experience to qualify for the rank of professor with tenure. Applications and nominations should be sent to the Search Committee Chairman, Dr. Jeffrey L. Hock, Electrical and Computer Engineering Department, Marquette University, Milwaukee, WI 53233. Review of resumes will start January 1, 1994, but will be accepted until the position is filled. Marquette University is an equal opportunity, affirmative action employer.

University of Idaho. The Department of Electrical Engineering invites applications and nominations for the position of Director of the Microelectronics Research Center (MRC) and associate or full professor of electrical engineering. This is a full-time, twelve-month, tenure-track position. The individual sought must have a doctoral degree in electrical engineering or closely related field, an established reputation in electrical or computer engineering, demonstrated administrative ability, a proven research record of publications and funding, and excellent teaching credentials. Preference will be given to candidates with expertise in VLSI design and applications. Due to NASA requirements the individual must be a U.S. citizen. A complete position description and further details can be obtained by calling Ms. Cherryl Sodorff at (208) 885-7665. Search and selection procedures will be closed when a sufficient number of qualified candidates have been identified, but not earlier than November 15, 1993. The University of Idaho is an equal opportunity/affirmative action employer and educational institution.

University of California, San Diego. The Department of Electrical and Computer Engineering may have open faculty positions in the areas of computer engineering, electronic systems and communications theory. You are invited to apply for anticipated tenure-track positions in these areas. The Computer Engineering/Electronic Systems position involves teaching and research in areas that include computer architecture, distributed computing, parallel computation, microprocessor and microcomputer design, design automation and VLSI architecture. The Communications Theory position involves teaching and research in the areas of statistical communications such as image modeling and processing, digital communication systems, detection theory, optical communications, etc. Candidates must have a Ph.D. and a strong interest in graduate and undergraduate teaching. Salary and rank are commensurate with experience and qualifications, and based on UC pay scales. Applications received by December 31, 1993 will be considered. Applicants should send a current resume and the names of at least three references to: Professor William S.C. Chang, Chair, Department of Electrical and Computer Engineering, University of California, San Diego, 8500 Gilman Dr., Mail Code 0407, La Jolla, California 92093-0407. Immigration status of non-citizens should be stated in the dossier. UCSD is an Equal Opportunity/Affirmative Action Employer.

The University of Southern California. The Electrical Engineering-Systems Department invites applications for several tenure track positions. Areas of interest include: communication networks; mobile communications; statistical communication and/or signal processing algorithms and their VLSI implementation; computer aided design for digital systems; computer architecture; multidimensional signal processing oriented toward image processing with an emphasis on compression, real-time acquisition, 3-D adaptive processing, fusion and understanding; array signal processing; intelligent control with emphasis on intelligent vehicles and highways. Applications must include a comprehensive resume, a list of three to five professional references, and a letter of interest indicating clearly the position designated above for which you are applying. Senior level applicants should have demonstrated leadership ability in building a strong research program, and have a distinguished teaching and research record. Please send material to Chairman, EE-Systems Search Committee, EE-Systems Department, Los Angeles, CA 90089-2560. USC is an Affirmative Action/Equal Opportunity Employer and encourages and welcomes applications from women and minorities.

Case Western Reserve University - The Department of Electrical Engineering and Applied Physics invites applications for a tenure track junior faculty position beginning Fall 1994. Applicants must have an earned Ph.D. in Electrical Engineering or related area, excellent academic credentials, the ability to teach at both the graduate and undergraduate levels, and a strong interest in pursuing a relevant research program. The department has research programs in solid state devices, circuits and fabrication, microelectromechanical systems, photonics, machine vision, control, robotics and neural networks. Send resume including names and addresses of at least three references to: Robert Trew, Chairman, Department of Electrical Engineering and Applied Physics, Case Western Reserve University, Cleveland, OH 44106. Telephone (216) 368-4088. Case Western Reserve University is an Equal Opportunity/Affirmative Action Employer.

University of Idaho invites applications for a tenure-track position at the assistant or associate level in the field of Computer Engineering. Areas of interest are VLSI design and applications, networking, parallel architectures, and information theory. Outstanding candidates in other specialties, particularly those with an emphasis on hardware implementations, may be considered. Qualifications include an earned Ph.D. in Electrical Engineering, Computer Engineering or a closely related field, excellent communication skills, a demonstrated commitment to teaching, the potential to establish a sponsored research program, and a strong background in one or more of the aforementioned specialty areas. Preference will be given to individuals with industrial experience. Applications, including a resume and the names of three references, should be sent to Dr. James Frenzel, Department of Electrical Engineering, University of Idaho, Moscow, ID 83844-1023. Search and selection procedures will be closed when a sufficient number of qualified candidates have been identified, but not earlier than December 20, 1993. The University of Idaho is an equal opportunity/affirmative action employer and educational institution.

University of Arizona. The University of Arizona Electrical and Computer Engineering Department invites applications for one or more possible tenure track faculty appointments for the 1994-95 academic year. Preference will be given to applicants at the Assistant Professor level, but exceptional candidates at higher levels may also be considered. In addition to an earned doctorate and a commitment to excellence in teaching at both the undergraduate and graduate levels, it is essential that candidates have outstanding research achievement and/or potential and the commitment and ability to establish an externally sponsored research program. Technical areas for 1994-95 recruiting are: (1) microelectronics/silicon integrated circuits including analog/digital circuit design and CAD tools; (2) computer network communications including interconnection networks for parallel processing systems. Applicants should send a resume, a statement of teaching and research interests, and a list of three references to Prof. K.F. Galloway, Department Head, Electrical and Computer Engineering Department, University of Arizona, Tucson, AZ 85721. Applications will be reviewed starting November 15, 1993 and will be received until open positions are filled. The University of Arizona is an Equal Opportunity/Affirmative Action Employer and specifically invites women and minorities to apply.

Bioengineering Faculty Position. University of Illinois at Chicago invites applications and nominations for a faculty position in the Bioengineering Program at either the junior or the senior level, with a starting date anytime during the 1994-95 academic year. The Bioengineering Program, one of the first such programs in the United States, offers degrees in Bioengineering at the B.S., M.S., and Ph.D. levels. Although candidates with competencies in any recognized area of Bioengineering will be considered, the Program has areas of concentration in Bioelectronics, Biomechanics, Biomedical Imaging Science, Biotransport, and Rehabilitation. Candidates must be active in research and must possess the Ph.D.

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degree in Bioengineering or in a related field. The appointee will hold a faculty position in one of the Departments in the College of Engineering - the particular Department will depend on the appointee's expertise and interests. Applicants should submit a curriculum vitae and the names of three references to: Irving F. Miller, Director, Bioengineering Program (M/C 063), University of Illinois at Chicago, 851 South Morgan Street, Room 1021, Chicago, IL 60607-7052. Applications will continue to be reviewed until the position is filled. The University of Illinois is an Equal Opportunity/Affirmative Action employer.

Brigham Young University. Computer Science Department, Assistant Professor. Applications are invited for an Assistant Professor position beginning September, 1994. Applicant must have a PhD and should have strong research orientation and scholarly ability. Current areas of research in our PhD and MS programs include User Interfaces, Neural Networks, MultiMedia, Communications/Networking, Software Engineering, Robotics, and Computer Vision. The Computer Science Department is housed in a new 54,000 square foot facility with well equipped teaching and research laboratories. Applicants should send a curriculum vita to E. Daniel Johnson, 3362 TMCB, Brigham Young University, Provo, Utah 84602. BYU is an EEO/AA employer and is sponsored by the Church of Jesus Christ of Latter Day Saints.

Iowa State University. The Department of Electrical Engineering and Computer Engineering invites applications for several tenure-track faculty positions. Applicants at all ranks will be considered. Starting dates are negotiable with preference given for Fall 1994. Primary needs are for specialization in the areas of analog VLSI, communications, signal processing, computer networks, distributed computing, real-time systems, and microelectronics. Responsibilities include teaching, research, and outreach. Salary and rank are commensurate with qualifications and experience. Requirements include a doctorate degree with a demonstrated potential for success in research and teaching. Applicants should send a resume with a statement of teaching, research, and outreach interests, as well as a list of three (3) references to: Chair, Faculty Search Committee, Department of Electrical Engineering and Computer Engineering, Iowa State University, Ames, Iowa 50011. Interviews will commence after February 1, 1994. Iowa State University is an Equal Opportunity/Affirmative Action Employer.

Gonzaga University in Spokane, Washington is seeking a faculty member with a strong background in the software and hardware digital design with emphasis on object-oriented system engineering. Responsibilities include teaching in an ABET accredited BSEE program and an MSEE program. Preference will be given to an individual with industrial design experience. An appointment will be made at the assistant or associate professor level. Only citizens or permanent residents of the United States will be considered. Candidates must have completed a Ph.D. degree. Gonzaga University is a Catholic, Jesuit institution with a commitment to teaching humanistic values to develop the whole person. The attractive, growing campus is set in an area of scenic beauty in the Inland Northwest. Send resume and list of three references to Dr. Grigore Braileanu, chair of the search committee, Department of Electrical Engineering, Gonzaga University, 502 E. Boone Ave., Spokane, WA 99258. Screening of applicants will begin January 3, 1994 and the expected appointment date is August 30, 1994. Gonzaga is an Equal Opportunity/Affirmative Action Employer.

The University of Florida, Department of Electrical Engineering, invites applications for a tenure track faculty position in the area of solid-state electronic circuits. Candidates are required to have a Ph.D. in electrical engineering or a related area. Potential faculty members are expected to develop a program of funded research in the area of their expertise as well as teach in that area. The anticipated beginning date is January 1, 1994. The University of Florida is an Affirmative Action Employer and women and minorities are encouraged to apply. According to Florida law, applications and meetings regarding applications are open to the public upon request. Please send applications with references to Dr. M.A. Uman, Chairman, Department of Electrical Engineering, 216 Larsen Hall, University of Florida, Gainesville, FL 32611. Applications must be postmarked no later than November 30, 1993.

Department of Electrical and Computer Engineering, Northeastern University in Boston seeks tenure track faculty, at all professional levels, in the areas of (1) Computer Engineering (computer architecture), software engineering, VLSI systems design for test and fault tolerance, (2) telecommunication networks, (3) digital signal processing and (4) microelectronics. The ECE Department currently has forty-seven full-time faculty, two nationally and internationally recognized research centers, a large and expanding graduate program, and sponsored research exceeding five million dollars annually. Expansive opportunities for research exist due to one of the highest concentrations of high technology in the nation. Ph.D. in Electrical Engineering, Computer Engineering, Computer Science or related field required with previous academic or industrial experience preferred. Salary and rank are commensurate with experience. Send resumes to: John G. Proakis, Chairman, Electrical and Computer Engineering, 309 Dana Research Building, Northeastern University, 360 Huntington Avenue, Boston, MA 02115. Northeastern is an Equal Opportunity/Affirmative Action, Title IX Employer.

The University of Florida, Department of Electrical Engineering, invites applications for a tenure track faculty position at the associated professor level that bridges the areas of electromagnetics and electric energy. Candidates are required to have a Ph.D. in electrical engineering or a related area, a strong background in atmospheric electricity, and a research specialty in lightning physics and protection. Potential faculty members are expected to develop a program of funded research in the area of their expertise as well as teach in those areas. The anticipated beginning date is January 1, 1994. The University of Florida is an Affirmative Action Employer and women and minorities are encouraged to apply. According to Florida law, applications and meetings regarding applications are open to the public upon request. Please send applications with references to Dr. M.A. Uman, Chairman, Department of Electrical Engineering, 216 Larsen Hall, University of Florida, Gainesville, FL 32611. Applications must be postmarked no later than November 30, 1993.

University of Wisconsin-Madison: The Department of Electrical and Computer Engineering anticipates the availability of a faculty position in one of the following areas: 1) Microwave devices and circuits. 2) Signal processing; an emphasis on applied aspects of signal processing is required. 3) Computer engineering. Qualifications include a Ph.D. degree and an outstanding academic and research record. Send resume and names of three references to Bahaa E. A. Saleh, Chairman, Department of Electrical and Computer Engineering, University of Wisconsin-Madison, WI 53706; an equal opportunity/affirmative action employer. Names, titles and/or occupations, and addresses of applicants and nominees cannot be kept confidential.

Worcester Polytechnic Institute-The Electrical and Computer Engineering Department invites applications for tenure track faculty positions in the following areas: (1) Telecommunications/Networks (especially wireless networks, local-area and broadband data networks); (2) Computer engineering (especially parallel and distributed processing, HDL, VLSI systems design, computer networks); (3) Analog Microelectronics. Candidates must possess an earned doctorate, and will be expected to have a strong commitment to high quality undergraduate and graduate engineering education, as well as to development of a research program. Applications from women and underrepresented groups are especially invited. Worcester Polytechnic Institute is a technical university offering project-oriented programs in Engineering, Science and Management. WPI is located in the high-tech region of east-central Massachusetts, with an enrollment of 2,500 undergraduate and 400 full-time graduate students. The ECE department has 23 full-time tenure-track faculty, and strong BS, MS, PhD, and research programs. Please send a statement of research and teaching interests, a resume, and a list of three references with addresses and telephone numbers to: Dr. John A. Orr, Head, ECE Department, Worcester Polytechnic Institute, Worcester, MA 01609. WPI is and Equal Opportunity/Affirmative Action Employer. Women and Minorities are encouraged to apply.

State University of New York at Buffalo - The Department of Electrical and Computer Engineering invites applications for anticipated faculty positions at all levels for September 1994. Applications will be considered in the following areas: solid state materials (including MBE or laser deposition), photonics, optical communications, VLSI design and computer engineering (particularly computer architecture, distributed systems, or optical networks). Send resume and names of four references before March 1, 1994 to professor Wayne A. Anderson, Department of Electrical and Computer Engineering, 208 Bell Hall, North Campus, State University of New York, Buffalo, NY 14260. Affirmative Action, Equal Opportunity Employer.

Postdoc in modeling GaAs or Si IC fabrication processes using neural networks. Background in statistics would be a plus. Send resume and names of three references to Dr. Jacek Zurada, Electr. Engrg Dept., University of Louisville, Louisville, KY 40292. UL is an EOE.

The Department of Computer Science and Information Systems at East Texas State University invites applications for the position of Department Head. The successful applicant should be able to continue development of both the undergraduate and graduate degree programs in Computer Science and Information Systems, to work with the 10 faculty department toward the goal of accreditation of the Computer Science program, and to expand scholarship and grants within the department. The Head will also be exptected to increase liaison with area industries, evaluate the need for new industry oriented programs or emphases, and seek support from external sources. Applicants should hold the Ph.D. in Computer Science or a closely related field, have demonstrated the ability to attract external funds, and have a teaching and research record commensurate with a tenured appointment at the rank of Associate or Full Professor. Industrial experience is desirable. Screening will begin December 15, 1993 and the starting date will be June 15, 1994. Send letter of application, vita, 3 current letters of reference, and an official transcipt of doctoral work to: Dr. Steve Razniak, Chair, Department Head Search Committee; College of Arts and Sciences; East Texas State University; Commerce, Texas 75429-3011. East Texas State University is a senior public institution, with an academic enrollment of approximately 8,000 students located in Commerce, Texas, 65 miles northeast of Dallas. This position is contingent on funding. This university is an Affirmative Action/Equal Opportunity Employer. Qualified women, minorities, and disabled persons are encouraged to apply.

Faculty Positions at CREOL. The Center for Research in Electro-Optics and Laser (CREOL) at the University of Central Florida is currently recruiting several faculty positions. CREOL is an interdisciplinary research center specializing in education and research in optics and lasers. Applicants should have a Ph.D. in Engineering, Physics, Chemistry, Materials Science or discipline related to electro-optics and lasers, and a demonstrated publication record. Faculty are sought in the areas of optical and laser research, optoelectronics and optical engineering including, image processng and display technology, materials research and processing, remote sensing, optical devices, optomechanics and photochemistry. Successful candidates are expected to teach one course per semester, pursue vigorous research programs, attract funding, and supervise masters and doctoral theses. Academic appointments are available through various departments participating in CREOL, e.g., Phys-

ics, Chemistry, Mechanical, and Electrical Engineering. Qualified applicants should submit a curriculum vitae, three letters of references, letter of interest outlining areas of research, and current external research support to: CREOL Screening Committee, Center for Research in Electro-Optics and Lasers (CREOL), University of Central Florida, 12424 Research Parkway, Suite 400, Orlando, FL 32826. UCF is an Equal Opportunity/Affirmative Action Employer.

Graduate Fellowships in Optics at CREOL. The Center for Research in Electro-Optics and Lasers (CREOL) at the University of Central Florida invites applications from highly qualified students for a number of CREOL Fellowships ranging from $11,000 to $15,000 per year. Exceptional students will be considered for additional Litton Fellowships of $4,000. Degrees of MS and Ph.D. in Optical Sciences and Engineering, Electrical Engineering, and Optical Physics are offered at UCF. CREOL has 28 faculty positions devoted to lasers and optical sciences and engineering. The academic program includes 25 specialized courses in electro-optics and lasers and optical materials as well as fundamental courses in Electrical Engineering, Physics, and Chemistry. Current research activities include: laser physics and engineering, such as tunable solid state lasers and free electron lasers; studies of nonlinear optical materials and processing no new laser host crystals and optical glasses; thin film optics, diffractive optics, infrared systems, optical design and image analysis, x-ray optics; and waveguide optics and devices; and laser applications, including laser materials processing, remote sensing, optical communications, x-ray lithography and microscopy. Completed applications are due by February 15, 1994. Applications from women, minorities and persons with disabilities are particularly encouraged. To receive an application package write to: CREOL - University of Central Florida, Graduate Affairs Committee, 12424 Research Parkway, Suite 400, Orlando, FL 32826.

Electrical Engineering: The Department of Electrical and Computer Engineering at the University of the Pacific is accepting applications for a tenure-track position at the Assistant or Associate Professor level. Applicants should have a Ph.D. in Electrical or Computer Engineering, or a related field. Undergraduate education is the primary responsibility; curriculum development, advising, MS-level teaching and clinic supervision, and scholarly activity/research are also expected. UOP is a private, comprehensive university with a total enrollment of approximately 4000 students. Send resume to: George Schroeder, Electrical and Computer Engineering, University of the Pacific, Stockton, CA 95211. UOP is an equal opportunity, affirmative action employer.

Monterrey Institute of Technology, Mexico City Campus, (ITESM), is looking for candidates for positions as professors in Electrical Engineering, Computer Science, Computer Engineering, Information Sciences, Informatics, and Telecommunications. Minimum requirements: Ph.D. or M.S. in Electrical Engineering with specialty in Electronics, Computer Science, Digital Systems, or Information Systems. Ability to teach in Spanish. Competitive salaries, good benefits, travel to and from Mexico. Starting date- January 1 and July, 1994. Send two copies of your resume, two copies of a letter of intent and transcripts to Dr. France J. Pruitt, U.S. Representative, P.O. Box 34430, Bethesda, MD 20827, Tel (301) 493-4982, Fax (301) 530-2461.

A Research Associate position in Magnetic Resonance Medical Imaging is available in the Department of Radiology, State University of New York, Stony Brook. A Ph.D. degree in Engineering, Physics, or related fields are required as well as a background in MR Imaging and image reconstruction. Applicants should send a detailed vita to: Prof. Z. Liang, Department of Radiology, HSC, Level 4, Rm 092, SUNY at Stony Brook, Stony Brook, NY 11794-8460. SUNY, Stony Brook is an affirmative action/equal opportunity educator and employer.

Faculty. University of Delaware, Department of Electrical Engineering, invites applications for the following tenure-track Assistant Professor positions: High-Performance Computer Engineering. We are presently seeking applicants for the position of tenure-track assistant professor in the area of high-performance computer engineering. We seek candidates with a strong interest in the architecture and the hardware implementation of advanced computer systems. Applicants must have a Ph.D. in electrical engineering or a closely related field. The successful applicant would be expected to carry out a vigorous research program in computer engineering and to teach and supervise students at both the undergraduate and graduate levels. The Electrical Engineering Department is well-equipped and maintains a large number of workstations for use in VLSI design, modeling and simulation, signal and image processing, and computer networking research. Excellent computer networking facilities are available, including department Ethernets and an 80 - megabit/second campus backbone connected to regional and national backbones. Electronic Devices and Materials. We also seek applicants for the position of tenure-track assistant professor in the area of electronic devices and materials. Applicants must have a Ph.D. in electrical engineering or a closely related field. We are looking for candidates with interest in innovative semiconductor optoelectronics or heterostructure devices. Candidates with a strong background in the applications of electromagnetics and quantum principles to these areas are particularly encouraged to apply. We are seeking a highly qualified person who is committed to a career in experimental research and teaching. The Department of Electrical Engineering has modern facilities for device processing and analysis, including Class 10 and Class 1000 clean rooms with a sub-micron mask aligner for device fabrication, an MBE crystal growth system, a 50 GHz network analyzer and wafer prober, and specialized laboratories with instrumentation for the evaluation of microwave and optical devices and materials characterization. Please send a resume, cover letter specifying position of interest, a description of research and teaching interests, and the names and addresses of three references to: Search Committee, Department of Electrical Engineering, University of Delaware, Newark, DE 19716. Review of applications will begin January 3, 1994. Applications will continue to be accepted until the positions are filled or until March 31, 1994. The University of Delaware is an Equal Opportunity Employer which encourages applications from Minority Group Members and Women.

Electrical Engineer: The University of Texas-Pan American, a comprehensive institution of 14,000 enrollment located along the Texas-Mexico border and serving a primarily Hispanic population, invites applications for tenure track positions (Assistant or Associate Professor) beginning September 1994. A doctoral degree in electrical engineering (or closely related discipline) is required. Professional registration and ABET accreditation experience are highly desired. Candidates should have experience in one or more of the following areas: devices, control systems, signal processing or electromagnetics. Duties include developing new courses and laboratories, teaching undergraduate courses, initiating research with undergraduates, directing groups of senior undergraduates in design projects, and serving on academic committees. Send current resume, copies of transcripts, and phone numbers of 3 professional references to: Director, Engineering Department, University of Texas-Pan American, 1201 W. University Dr., Edinburg, TX 78539, or call (210) 381-3510 for details. Closing date: February 1, 1994. UT-Pan American is an EEO/Affirmative Action Employer.

The University of Maryland's Institute for Systems Research (ISR) invites qualified applicants for a Senior Research Scientist position. Created in 1985 as one of the first NSF Engineering Research centers, the ISR has established an exceptional cross-disciplinary research program focusing on automation and information engineering systems. ISR has exceptional lab facilities and strong interests in education innovation and research. Close collaboration with industry, government research labs, and leading research institutes abroad provides a rich and exciting environment. Prospective candidates should have broad research experience in satellite communications, a strong industry background, and familiarity with academia. A strong history of contributions to the design and architecture of satellite communication systems, a deep understanding of communication networks, and knowledge of regulatory issues in satellite and wireless communications are essential. The individual is expected to work with project teams at the NASA CCDS on satellite and hybrid communications within the ISR and contribute to its major activities. Submit by December 31, 1993 resume, list of publications, and references to: Research Scientist Search, Institute for Systems Research, 2175 A.V. Williams Building, University of Maryland, College Park, MD 20742. The University of Maryland is an equal opportunity employer.

Tufts University/New England Eye Center, Biomedical Optics and Lasers, Research Faculty Position. Tufts Electro-Optics Technology Center and New England Eye Center seek candidates for a twelve-month full-time position, presently non-tenure track with possible future conversion to tenure track. Candidate will provide leadership in developing a teaching and sponsored research program in lasers and optics for medicine. PhD in Electrical Engineering or Physics and demonstrated ability to do experimental research. Preference to candidates with research and teaching experience in biomedical optics and lasers. Send curriculum vita and list of 3 references to Professor Paul Kelley, Acting Director, Electro-Optics Technology Center, Tufts University, 4 Colby St., Medford, MA 02155. Screening of applications will begin November 20, 1993. Tufts University is an Affirmative Action/Equal Opportunity Employer.

University of Colorado at Denver Faculty Positions. The Department of Electrical Engineering is accepting applications for tenure-track positions for Fall 1994 in the areas of Communications, Digital/Computer Engineering, Control Systems, and Power, contingent upon funding. Candidates must have an earned Ph.D., at the time of employment with an established publication and research record. Teaching and industry experience are preferred. CU-Denver is the urban campus of the University of Colorado with both undergraduate and graduate programs. Please send resume and names, addresses, and telephone numbers of at least three references to Douglas Ross, Chair of the Search Committee, Department of Electrical Engineering, University of Colorado at Denver, Denver, CO 80217-3364. Applications must be received by 1 March, 1994. The University of Colorado at Denver is committed to enhancing the diversity of its administration, faculty and staff and invites and strongly encourages nominations of and applications from women and members of ethnic minority groups, veterans and people with disabilities. Alternative formats of this ad are available upon request for people with disabilities.

University of Houston. The Department of Electrical Engineering invites applications for tenure-track positions in all primary fields of electrical engineering. Research areas of particular interest include High Performance Computing and Parallel Architectures. Please send resumes to Dr. J.C. Wolfe, Department of Electrical Engineering, University of Houston, Houston, Texas 77204-4793. An Equal Opportunity Employer.

GMI Engineering & Management Institute invites applications for a tenure-track position in physics at the level of assistant professor. Exceptional candidates may be considered for appointment at higher rank. The Physics Division is seeking to strengthen its capabilities in optics, lasers, and materials science, with the intent to offer degree programs in applied physics and optics. The successful candidate must hold a Ph.D. in physics, optics, or a related discipline and show evidence of outstanding ability to teach physics at all undergraduate levels, the capability to conduct research in an undergraduate environment, and the versatility to interact with colleagues in a multidisciplinary environment. The candidate must have proof of legal authority to work in the U.S. Please send resume, statement of research objectives, and arrange to have three (3) letters of reference sent to: Dr. Richard Bolander, Physics Faculty Search Committee Chair, Science and Mathematics Department, GMI Engineering & Management Institute, 1700 W. Third Avenue, Flint, MI 48504-4898. Review of applications will commence immediately. To ensure full consideration, applications must be received by February 1, 1994. The appointment

commences September 16, 1994. GMI, founded in 1919, operates on a five-year fully cooperative plan of education. Undergraduate students alternate twelve weeks of classroom and laboratory studies with work experience at business and industrial organizations in approximately 600 locations world-wide. The Science and Mathematics Department offers ■ Bachelor of Science degree in Applied Mathematics as well as minors in Applied Chemistry, Applied Mathematics, Applied Optics and Computer Science. GMI is an affirmative action/equal opportunity employer and actively seeks the candidacy of women and minorities. GMI is a smoke free facility.

Control Engineering Faculty Position in the Department of Systems, Control and Industrial Engineering, The Case School of Engineering, Case Western Reserve University, Cleveland Ohio. Applications are invited for a tenure-track faculty position at the Assistant or Associate Professor level. The position will be available in August 1994. Candidates should have ■ strong analytical background, a dedication to quality education at the undergraduate and graduate level and the expertise and potential for developing a funded research program in control theory and its applications. Applicants must have a Ph.D. degree in engineering or a closely related field. The Department is also recruiting for ■ tenure track position in the field of industrial engineering. The Department of Systems, Control and Industrial Engineering has eight full-time faculty, 60 undergraduate students and 60 graduate students and offers B.S., M.S. and Ph.D. degree programs in Systems and Control Engineering and offers a B.S. degree program in Industrial Engineering. The Department specializes in control systems, mathematical systems theory, optimization, decision making, simulation, large scale systems, stochastic modeling and production/manufacturing systems. Interdisciplinary research is conducted through interdepartmental centers in the areas of automation, intelligent systems, and sensors. CWRU is an equal opportunity/affirmative action employer. Applications (including a list of three references) should be sent to Prof. Kenneth A. Loparo, Chair, Department of Systems, Control and Industrial Engineering, 603 Crawford Hall, The Case School of Engineering, Case Western Reserve University, Cleveland, OH 44106-7070.

Doctoral Assistantships. The Department of Electrical and Computer Engineering at Old Dominion University invites applications for graduate research and teaching assistantships. Highly qualified students completing ■ master's degree in electrical engineering, computer engineering, physics, material science, or computer science who are interested in pursuing a Ph.D. in electrical engineering are encouraged to apply. Available research areas include fiber optic sensors, ultrafast surface science, laser induced shocks, optoacoustics, laser spectroscopy, robust control systems, sic devices, parallel processing, and speech communication. Contact Dr. V.K. Lakdawala, Graduate Program Director, Department of Electrical and Computer Engineering, Old Dominion University, Norfolk, VA 23529-0246.

Carnegie Mellon—Graduate Study in Engineering and Public Policy (EPP): The EPP Graduate Program leads to a research-based Ph.D. specializing in such telecommunications policy areas as: approaches to building telecommunications infrastructure, and issues related to wireless telecommunications systems. Applicants must hold ■ BA or BS in engineering, physical sciences, or math. Education or experience beyond the BS very desirable. Contact Denise Murrin-Macey, Engineering and Public Policy (15), Carnegie Mellon University, Pittsburgh, PA 15213.

Government/Industry Positions Open

Engineer I: hydroelectric hardware and software design and testing of embedded computer systems with applications in automobile power train controllers. Preparing written technical reports. Job requires minimum of Bachelor's Degree in Electrical Engineering. Required minimum of 4 credit hours each in Computer Architecture and Digital Circuit Design. Minimum of 3 credit hours of Embedded System Design and Applications Lab. Minimum of 4 credit hours of VLSI or equivalent course. University level technical writing class of 3 credit hours. 40 hr/wk, 8:30 a.m. - 5:00 p.m.; $20 per hour-$30 per hour OT. Send resumes to 7310 Woodward Avenue, Room 415, Detroit, MI 48202. Reference Number 71393. "Employer Paid Ad."

Electrical Engineer to design, plan, and oversee manufacture, construction, installation, operation, and maintenance of electric or electronic components, equipment, systems, facilities, and machinery used in the generation, transmission, distribution, and utilization of electrical energy for domestic, commercial, and industrial consumption; work closely with other engineering disciplines in the development and application of robotics to increase production quality, efficiency, and volume. Require Bachelor's degree in Electrical Engineering and 2 yrs exp. as an Electrical Technician. Bachelor's level coursework must have included Design of Electrical Equipment, Uncontrolled Electrical Equipment of Automatics, and Testing and Safety of Electrical Equipment. Experience must include modernization and maintenance of electrical systems and electrical safety systems. 40 hr wk. 9am-5pm. $34,020/yr. Send resumes to 7310 Woodward Avenue, Room 415, Detroit, Michigan 48202, Ref. No. 63993. Employer Paid Ad.

Electrical Engineer: An entry-level growth opportunity in manufacturing of MRI gradient coils is available for an electrical engineer or instrumentation physicist with a strong hands-on orientation and excellent academic credentials. Minimum requirements: 1 year electronics repair experience, electromagnetics, C++ programming. Experience with MRI, NMR, rf electronics, and precision machine tooling also desirable. Send resume including copies of transcripts and GRE or SAT scores to: Judy Doty, Doty Scientific, Inc., 700 Clemson Rd., Columbia, SC 29223.

!!!Attention Japanese Speakers!!! Learning Group International, the world's leader in advanced technical training, is looking for technical professionals to be trained and used to teach our week-long courses in Japan. We currently need instructors in the areas of Software Engineering, Object-oriented Analysis and Design, Software Project Management, Open Systems, Client-Server Systems, and Netware. Fluency in Japanese is required. Must be available a minimum of 3 weeks per year. Please send resumes to Michael Lopez, Learning Group Int'l 6053 W. Century Blvd., #200 LA, CA 90045. Tel (310)417-9700, Fax (310)645-4762.

Lawrence Berkeley Laboratory Center for Functional Imaging. NIH/NRSA postdoctoral position available to engage in mathematical and statistical analysis of data from PET (positron emission tomograph) and SPECT (single photon emission tomograph) machines. A recent Ph.D. in a relevant field is required. Appropriate fields include Mathematics, Biophysics, Computer Science, Bioengineering, or Physics. Programming experience with the UNIX operating system and the X window system is desirable. U.S. citizenship or permanent resident status required. Send resume and names of three references to: Dr. Ronald H. Huesman, c/o Lawrence Berkeley Laboratory, Staffing Office, Box #JIEE1691, Bldg. 938A, Berkeley, CA 94720. LBL is an equal opportunity employer. Women and minorities are encouraged to apply.

Engineer, Staff Engineer, Software Systems: Will develop and implement voice capability and features (e.g. voice compression, text-to-speech, speech recognition) for microprocessor/Digital Signal Processor related products. This position requires development of voice compression algorithms, simulation and real time implementations. Future duties will include implementation of current digital voice standards and research of newly developed standards, and development of text-to-speech algorithms and voice recognition algorithms. Requires Ph.D. in Electrical Engineering. Must have 1-1/2 years industrial experience directly relating to the following: software development tools for general purpose digital signal processing (DSP), software systems design, DSP-based real time implementation and testing, current speech coding industrial standards, and cellular industrial standards (e.g. IS-54, GSM). Must also have academic coursework/practical experience in speech signal processing products (e.g. speech coding, text-to-speech, speech recognition), and algorithm simulation. $5,600/month, 40 hrs./wk. Qualif. applicants send resume or application letter with ad to: AZ DES Job Service Attn: 732A, Re: 0083452, P.O. Box 6123, Phoenix, AZ 85005. Job Location: Chandler, AZ. Emp. pd. ad. Proof of authorization to work in U.S. required if hired. The company is an equal opportunity employer and fully support affirmative action practices.

Electrical Engineer II - Research & design electrical components & systems for telecomm equip & control instrumentation for mfg. automization. Direct engineering personnel in test apparatus & equip. Determine methods, procedures & conditions for testing. Develop applications for prototypes. Initiate modification for client specifications. Oversee implementation of product from design through production. Liaise w/package designers & customers incl mgt. to discuss needs & make recommendations on product development. BS Math or EE, and MSEE; 2 yrs. exp as EEII or EE; plus: worked with Autocad, Acad & Orcad software; worked w/ theories & analysis in telecomm & control instrumentation design, supervised telecomm & control instrument engineering personnel and function. Must have used international standards of quality, safety & compatibility as regd by European governments & non-government entities. $36635/yr.; 40 hrs/wk, 7:30AM-5:00PM. Interview Job Site: Monroe, WI. If offered job, must show legal right to work. Send 2 resumes to job #930181, Mary de Bruin, Monroe Job Service Office, 1518 1/2 11th Street, Monroe, WI 53566.

Electrical Controls Engineer. Challenging opportunity with leading packaging machinery manufacturer. Position requires a B.S.E.E. and a minimum of 3 yrs experience in the design and programming of industrial automation controls. Allen Bradley experience very helpful. Excellent salary and fringe benefits. Send resume including salary requirements in complete confidence to: National Instrument Co., 4119 Fordleigh Rd., Baltimore, MD 21215, Attn: Jack Grosskopf. Fax 410-764-7719.

MRI/NMR Applications Scientist: An excellent, high-visibility growth opportunity is now available in ■ small, growing company known for innovation in NMR instrumentation. Minimum requirements: Ph.D. in bio-physics, chemical physics, medical physics, or electrical engineering, including research and experience in MRI and NMR. Instrumentation development experience also required. Send CV to: Dr. David Doty, Doty Scientific, Inc., 700 Clemson Rd., SC 29223.

Deposition Scientist; 40 hrs./week; $50,000/yr. Development of optical diagnostics and their application to diamond film deposition processes. Design, set-up and operation of laser induced fluorescence, fluorescent imaging, incoherent Raman spectroscopy, coherent Raman spectroscopy, optical absorption spectroscopy and multiphoton ionization spectroscopy. Req. Ph.D. in physics with 1 year exp. in job offered or 1 yr. exp. as Post Doctoral Research Associate. Ph.D. in physics must be w/emphasis on laser based techniques for measurement of gas phase molecular & radical concentrations. Must have exp. in operation & maint. of high power pulsed Nd: Yag lasers, pulsed dye lasers & harmonic generations necessary. Knowl. of and ability to minimize difficulties & hazards of implementing res. techniques in industrial or pilot plant facility must be demonstrated. Familiarity w/ comp. hardware used for data acquisition & data systems, optical detection schemes & data analysis to dc plasma arc systems. Must have extensive theoretical and practical knowledge of lasers, laser spectroscopy and optics. Thorough understanding of and experience with linear and nonlinear light-matter interactions. Familiarity with electronics related optical detection schemes.

Experience in successfully transferring a laboratory proven technique to industrial facilities. Ability to scale-up selected diagnostics to hostile industrial environments, and to assume responsibility, education, and supervision in order to assure the safety of the industrial staff, regarding the hazards related to the technique. Job site & interview in Irvine, CA. Reply by resume with copy of this ad to: J.O. No. LW20200, P.O. Box 269065; Sacramento, CA 95826-9065. Must show legal proof of right to work permanently in the U.S.

Eesof Incorporated is seeking successful engineers! Join our engineers in creating high frequency analog software that continually challenges current standards for ease-of-use productivity. Member of Technical Staff positions required MSEE or PhD Ee for the following: 1) To design, develop, and maintain RF/MW synthesis tools. Requires: exp. in design automation or analog/RF/MW circuit and system design; "C"; UNIX; knowledge of analog/RF/MW synthesis and exp. w/Libra and/or Omnisys desirable. 2) To design and develop electromagnetic simulation tools for analysis of MMIC circuits and their pkgs. Requires: a concentration on the numeric solution of EM problems; exp. in implementation and application of EM simulators for circuits, time- & frequency-domain methods, and "C". 3) To continue the development of high-frequency circuit simulation software, simulation algorithm and element models. Requires: 1 + yrs. in any of the following areas, high-frequency analog circuit simulation, algorithm development, or passive/active device modeling with knowledge of "C". EEsof offers competitive compensation and full benefits in a successful, rapidly-growing company. If qualified, send resumes (principals only), in confidence, to: EEsof, Attn: IEEE-1193, 5601 Lindero Cyn. Rd., Westlake Village, CA 91362. Or fax to: 818/879-6212.

Technical Marketing Specialist: Responsible for: formulating and developing product marketing and business strategies and plans for Land Mobile Radio Systems, including customer development and stratetic partnerships; supporting implementation of such marketing and business strategies by increasing both the quantity and quality of customer base as measured by long-term sales; working with marketing and sales personnel worldwide to prepare competitive applications analysis; publishing such analysis for business consumption; developing future products and support functions for Land Mobile Radio Systems by analyzing customer information, specifications and needs and analyzing competitive products and systems; training regional marketing and sales personnel and Land Mobile Radio Systems Sales Engineers on the technical and strategic aspects of new products and features for the Land Mobile Radio Systems; and developing technical sales materials for Regional Marketing and Sales Personnel. Minimum Education Requirements: Equivalent of Bachelor's degree with [illegible] major field of study in Electrical Engineering Technology, Electrical Engineering or a related field. Required Related Occupation Experience: Five years experience as Technical Marketing Specialist performing the above-mentioned job duties or five years related occupation experience as Technical Marketing Specialist-Land Mobile Radio Systems and Applications. Other Special Requirements: Required Related Occupation Experience Must Include: Five (5) years of marketing and sales experience in Land Mobile Radio Systems and Land Mobile Radio Applications, including dispatch, telephony, microwave frequency and microwave multiplexers, Or In The Alternative, three (3) years of marketing and sales experience in Land Mobile Radio Systems and Land Mobile Radio Applications, including dispatch, telephony, microwave frequency and microwave multiplexers and a Master's Degree in Business Administration. Must be able to travel internationally and up to twenty-five percent (25%) of the time. Salary and Hours of Work: 40 hours per week, 8:00 a.m. to 5:00 p.m.; $46,645 per year. Location: Job in Lynchburg, Virginia. Mail resumes with copy of Ad attached to VEC, VA3091622, P.O. Box 61, Roanoke, VA 24002-0061.

Human Brain Signal Analysis: SF NEUROTECHNOLOGY™ co. needs Lead PC Scientific Programmer to create a system for brain signal analysis. Five yrs min. comm'l exper in PC s/w design & development for scientific appls req. 2 yrs min. exper. req. w/ MS-Windows (VXDs, OLE, DLLs). Familiarity with Win32 concepts req. Exper w/ s/w spec, Q/A, proj mgmt, signal processing appls, 3-D graphics, real-time data acq sys, C++, & db prog. also needed. Tremendous career growth opportunity for those interested in the human brain! Send resume to: SAM Technology, 51 Federal St., SF, CA 94107; email: jane@eeg.com; Fax: (415) 546-7122.

Software Engineers. Primary languate is C/C++ operating in UNIX/X Windows environment on VME-based Sun workstations. Design, code, and test real-time imagery and signals software. Use of commercial GUI tools (such [illegible] Motif). Working knowledge of ADA is a plus. Familiarity with DOD-STD-2167A software development methodologies. Hands-on experience with hardware/software integration. Th[illegible] to five years experience to include 3 years on Sun/UNIX-based real-time image/signal processing. BS in EE, Math, or CS required. Secret Clearance desired. California Microwave, Inc. is [illegible] leader in satellite and wireless communications, airborne surveillance systems, and multi-sensor fusion. The Airborne Systems Integration Division near Aberdeen, Maryland is in search of talented engineers to staff existing programs and to pursue emerging programs. Qualified software engineers and other engineering professionals may forward resume to: California Microwave, Inc., Attn: Human Resources, P.O. Box 358, Belcamp, Maryland 21017. U.S. Citizenship Required. EEO/AA/M/F/H/V.

Software Development Engineer (Bothell, WA). Eval use of TCP/IP, SNMP, OSI, SS7 & other standard protocols in netwk mgmnt prods for mgmnt of comm netwks & how they would be supported by netwk elements, i.e. telecomm devices. Develop alternatives for implementation of standard protocols. Develop software for integratin of purchsed protocol implementations using C & C++. Develop recommendations for handling 16-bit character interfaces in netwk mgmt control software sybsysts. Remain abreast of chngs in industry standard comm technology that impacts delivery of competitive prods. MS in Computer Science & 2 yrs in job or as System/Network/Software Engineer. Exp specified must incl development of data comm software for UNIX inclg TCP/IP w/SNMP; implementation of UNIX, C, C++, X-Windows, SQL databases; development of graphical user interfaces & databases in client/server environ. Exp must also incl development of software for support of telephony systs & comm mgmnt interfaces for telecomm switches. 40 hrs/wk, 8 am-5 pm; $46,000/yr. Must have proof of legal author to work in US. Send res by 12/4/93 to: Employment Security Dept E&T Div, JOB#385124 P.O. Box 9046, Olympia, WA 98507-9046.

Engineer, Design: Design and dev GaAs FET amplifiers, freq multipliers, oscillators & linearizers for microwave & millimeter wave frequences. PhD or equiv foreign degree in EE or Electronics; + 2 yrs epx in job ofrd or microwave-relat design, research or eng reqd. $5616/mo. 40 hr/wk. Exp w/ microwave device model, CAD tools (Spice, Touchstone), propagation structures (coaxial, microstrip, slotline, waveguide), telecomm sybsys design, & design of amplifier, oscillator, mixer, harmonic oscillator & freq multiplier circ reqd. Knlg of GaAs tech reqd. Job site/intrv: San Jose, CA. Send resume to: DSE Confidential Reply Service, Dept. 374, 601 Gateway Blvd., Ste. 950, South San Francisco, CA 94080.

Senior Software Engineer for design/manufacturer of aerospace industrial instrumentation to provide technical leadership, participate in design and development of process control software which meets quality, cost performance and schedule goals. Establish technological requirements, make appropriate tradeoffs, write specifications, generate and test code and verify final performance to specifications. Establish and maintain schedule and cost objectives, and provide technical work direction including supervision of engineers. Requirements: Masters in Electrical Engineering; 4 yrs exp. in the job offered or as Software Engineer with the required years of exp. in the development of process control applications. At least two of the required years must be in a UNIX based software development environment using "C" programming language. M - F, [illegible] - 5, $48,000 p.a. Must be authorized for permanent employment in the U.S. Send this ad w/resume and cover letter to: S. Springmeyer #3-134, MDJT - Room 203, 777 East Lake St., Minneapolis, MN 55407. EOE.

Manager, Electrical/Electronic Dept. for mftr in NE Ohio. Supervise, direct and coordinate operation, maintenance and repair of various machineries for manufacture of baby diapers, including glue applicator machine, super absorbent applicators (SAP) and related support equipment, which utilize very high-speed process, high speed sensors, high voltage motors, step motor controls and speed controls (AC and DC). 4 years college with Bachelors Degree in Electrical Engineering. 2 years experience required in job offered. 40 hr/wk, 9am - 5pm, Mon-Fri, $50,540/yr. Must have legal authority to work indefinitely in the U.S. Send resume in duplicate (no calls) to J. Davies, JO#1329638, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, OH 43216. An employer paid ad.

Government/Industry Positions Wanted

BSEE, Cum Laude Graduate, (3.9/4.0 EE GPA) seeks position dealing with the transmission [illegible] distribution of electric energy (618) 654 9427.

M.S.E.E. (1993). Entry-level Sales/Engg. position. VLSI, Signal/Image Processing; DOS, UNIX, C, Mathcad. Excellent communication/written skills. (708)893-0776; Fax (708)893-0789.

MIT

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Materials Engineering

The MIT Department of Materials Science and Engineering has searches in progress for tenure track Assistant Professors. Faculty members are sought with demonstrated potential, creativity and teaching ability in an aspect of the field of materials science and engineering. These positions are potentially open for persons specializing in any of the materials classes (metals, ceramics, polymers or electronic materials), or more broadly in materials science or materials engineering.

Doctorate required and experience desirable. Salaries and benefits competitive. Positions will be filled only if exceptional candidates are found. Appointment to a more senior position is possible based on experience and accomplishments.

Interested persons should send a complete resume including a list of publications and names and addresses of three persons who could supply letters of reference. This material should be sent to: ***Professor Merton C. Flemings, Head, Department of Materials Science and Engineering, Massachusetts Institute of Technology, Building 8-309, 77 Massachusetts Avenue, Cambridge, MA 02139-4307.***

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Scanning
The Institute

Improved IEEE credit card

The IEEE has selected a new vendor for its Visa and MasterCard program. Primerica Bank of Wilmington, DE, will now provide a credit card that offers members and their families much better credit terms. These terms, which went into effect on Sept. 28, include:

- No annual fee.
- An annual percentage rate (APR) of 8.9 percent for those who transfer the balance from their current credit cards to the new one by Jan. 15, 1994.
- A competitive variable interest rate of 12.9 percent.

In benefits to the member, this card outdoes every other available credit card, said IEEE executive director and general manager John Powers. In addition, he said, "It will reduce our dependency on member dues—as many members have already noticed when they received their 1994 membership renewal, which contained no dues increase."

The decision not to renew the Institute's contract with MBNA of Newark, DE, was made after an extensive evaluation of other credit card carriers. The NMBA credit card, it was found, simply did not offer the best terms to IEEE members or the Institute.

Fellow kits ready

Nomination kits for the 1995 class of IEEE Fellows are now available in both traditional and electronic versions. The deadline for receiving nominations is April 15, 1994.

For the traditional kit, contact Staff Secretary, IEEE Fellow Committee, 345 E. 47th St., New York, NY 10017; 212-705-7750; fax, 212-223-2911.

For a disk with the electronic version, which requires a LateX document processor on a Unix system, contact the IEEE Department of Awards and Recognition at the above address; 212-705-7816; fax, 212-752-4929; e-mail, j.biley@ieee.org.

Consultants meet in Connecticut

The second conference of the IEEE Consultants' Network is being hosted by its Connecticut chapter at the Hartford campus of the University of Connecticut on Nov. 20. The agenda includes workshops on marketing, insurance, legal issues, referral services, business planning, and vendor contacts.

The Private Practitioners Task Force, chartered by the U.S. Activities Board of the IEEE to represent independent consultants' networks throughout the United States, will meet at the same location on Nov. 21. Contact Russell Lundeberg, 203-561-0833, or Charles Pasquariello, 203-265-3019.

Coming
in Spectrum

SEE HOW THE NEW CHIPS RUN. Chip makers and software houses have been exceptionally active this year in bringing new microprocessors and operating systems to market. This article reports on the performance strengths and weaknesses of chips like Pentium, PowerPC, and Alpha. Also examined: the latest versions of OS/2, Windows, and Unix operating systems.

SUPERCONDUCTORS IN BULK. Having reviewed efforts around the world, this author concludes that high-temperature superconducting wire is indeed close to making its debut in commercial applications like the design of magnets and electric power equipment. In the van is the breakthrough in fabricating superconducting wire.

INTELLIGENT HIGHWAYS. Drivers of cars and trucks may soon have extra help in reaching their destinations thanks to the power of computers and communications. This overview of progress describes present projects and future prospects.

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i860 DSP?

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Faster than C40, C30, 96K

	ALACRON			Sonitech	Ariel	Spectrum
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Chip	Dual i860XP	i860XP	i860XR	TMS320C30	M96002	TMS320C40
Clock(MHz)	50	50	40	33	33	40
Memory	2 MB(d)	2 MB(d)	2 MB(d)	256 KB(s)	64 KB(s), 1 MB(d)	640 KB(s)
Mflops	200	100	80	33	50	40
IK FFT(usec)	320	547	730	2900	1100	1925
$/Mflop	**$56**	**$83**	**$84**	**$88**	**$94**	**$182**

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Memory: d = dram, s = sram. All product information provided by respective manufacturers in January 1993.

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